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DEVELOPMENT OF ASTRONOMY IN THE USSR

(FIFTY YEARS OF SOVIET SCIENCE AND TECHNOLOGY)

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DEVELOPMENT OF ASTRONOMY IN THE USSR (FIFTY YEARS OF SOVIET SCIENCE AND TECHNOLOGY)

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RADIO ASTRONOMY

Invention of the radio by our great compatriot A. S. Popov laid the road to development of a number of contemporary branches of science. This includes a branch of astronomy – radio astronomy.

In contrast to other instrument methods radio astronomy has obtained a certain independent value. This happened partly as a result of an essential expansion of the range of observed cosmic radiation, partly due to the complexity of the actual method, connected with solving the most difficult problems of radio physics, radio engineering and electronics and other neighboring disciplines.

Radio astronomical methods of study essentially enriched our knowledge about the nature of the Universe. Development of radio astronomy powerfully influenced the solution of such important problems of natural science as the nature and origin of cosmic ray primaries, investigation of physical mechanisms of radiation, cosmologic problems, etc.

Radio astronomy in the Soviet Union began in the first postwar years. The first radio astronomical experiments are intimately connected with the name of that remarkable Soviet scientist N. D. Papaleksi (1880-1947). Even in 1928 Papaleksi with L. I. Mandel'shtamom using the results of measurements of radio wave reflections from the upper layers of the earth's atmosphere calculated the possibility of using radar with the moon. However,

in that time technical possibilities of transmitting equipment did not allow a similar experiment. Only rapid development of radar technology during the years of the second world war ensured the necessary powers and means for radar examination of the moon's surface. In 1946 appeared publications about the results of radar examination of the moon carried out in the United States. In that same year in "Progress in Physical Sciences" a long article by N. D. Papaleksi was printed, "Measurement of the distance from earth to moon using electromagnetic waves," in which a detailed analysis is made of the possibilities of the radar method for astronomical measurements. N. D. Papaleksi showed that using radar it is possible to measure the distance to the moon with greater accuracy by an order than that attained in astronomy. This article of N. D. Papaleksi laid the theoretical bases of radar astronomy, so successfully developed in the USSR in recent years. It is interesting to note that in this article he discussed the possibilities of optical location of the moon, anticipating an experiment carried out only in recent years using lasers.

Already at the end of the 1940's great interest toward radio astronomical investigations was manifested in the whole world. Work of the English military engineer Hey and his colleagues, which in 1942-1945 established that the sun constitutes a source of radio emission, became well-known. First results of measurements of radio emission of the sun did not go unnoticed by Soviet astronomers and physicists. During this time the young Soviet scientists V. L. Ginzburg and I. S. Shklovskiy on the basis of data from observations of solar radio emission obtained by the English in 1942-1946 independently studied the possible mechanisms of radio emission of the sun. They made the fundamental theoretical conclusion that the source of radio emission of the sun is not the solar photosphere, but the external layers of the solar atmosphere — chromosphere and corona. Simultaneously the same result was reached by the Englishman D. Martin. Created on the basis of theoretical calculations of V. L. Ginzburg, I. S. Shklovskiy and D. Martin, the so-called isothermal model of the solar atmosphere, explaining thermal radio emission of the sun, is now classical and is the basis for the theory of radio emission of the sun.

Thus, by 1947 there already were defined achievements in development of the theory of radio emission of our main star. N. D. Papaleksi was interested in the possibility of an experimental check of the above theoretical propositions. Suitable for this purpose was the solar eclipse which was to occur 20 May 1947. Considering the insufficient resolving power of the existing antenna arrays use of a natural "diaphragm" — the moon during the solar eclipse gave brilliant possibilities for detailed investigation of the distribution of brightness of radio emission across the solar disk. With his inherent energy Papaleksi carried out extensive work on organization of the overall expedition of Academy of Sciences USSR for observation of the eclipse. Selection of place fell on Brazil, where the solar eclipse would be total.

On the initiative of N. D. Papaleksi an expedition to Brazil was organized to observe a total solar eclipse. The radio astronomical group in the expedition had to conduct their measurements directly on board ship.

In a letter of N. D. Papaleksi to P. P. Shirshov dated 2 December 1946 requesting a particular ship for the expedition we read: "On the deck of the ship will be a special device for observing the solar eclipse and studying radio emission of the solar corona."[1] At the disposal of the expedition was the diesel ship "Griboyedov." Preparation went at full speed. However, the initiator and main organizer of the expedition was not predestined to take part in it. Papaleksi died 3 February 1947.

Nikolay Dmitriyevich Papaleksi rightfully can be considered the founder of Soviet radio astronomy. He clearly saw prospects of development of this new field of knowledge. Shortly before his death, in a public lecture on the subject "Contemporary Radio and Science" Papaleksi said: "This new region of study, which now is

[1]Archives of the Radio Council Academy of Sciences USSR. No. 68, p. 3 Vol., 1946-1947.

Nikolay Dmitriyevich
Papaleksi

1880-1947

in its infant stage, unconditionally presents extraordinary interest for solar physics. There is every basis to think that with the use of radio methods for astronomy a new era will be opened, which in its significance can be compared with the discovery of the Fraunhofer lines and application of spectroscopy in astrophysics and which will help us to penetrate still deeper the secrets of the universe."

Even before the actual departure of the Brazilian expedition the leadership of the radio astronomical group fell upon S. E. Khaykin. As in any new experiment, during the observations it was necessary to surmount different difficulties. For observations an installation on a wavelength of 1.5 m was used with a broadside antenna array consisting of 96 dipoles with an overall area near 80 m^2. Practically the most difficult problem was the almost

3 hours of antenna rotation following the sun's motion. The antenna was set up on a ship in such a way that with the help of ship winches it was possible to turn it on its horizontal axis at the angle of elevation (with respect to height). To track the sun through the azimuth the whole ship had to turn together with the antenna. This movement had to be carried out with great accuracy. Such a maneuver was unusual, complicated by the possible influence of wind and sea disturbances.

20 May 1947 S. E. Khaykin and B. M. Chikhachev conducted the first observations in the USSR of radio emission of the sun during a total solar eclipse. The first radio astronomical experiment, carried out by Soviet radio astronomers, brought valuable scientific results. During the full phase of the eclipse, when intensity of the optical radiation decreased by a factor of 10^6, the intensity of radio emission fell only by a factor of 2. This phenomenon brilliantly confirmed the theoretical conclusion concerning the mechanism of thermal solar radiation in the radio frequency band, according to which in the meter range the basic source of radio emission of the sun must be the coronal layers of the solar atmosphere.

During treatment of the data from radio observations the first comparison with optical data was made. The results of radio astronomical experiments during the Brazilian expedition had a great methodical value. During all subsequent eclipse radio observations of the sun essentially the method of the first experiment has been used.

Upon completion of the Brazilian expedition S. E. Khaykin became head of the work on radio astronomy at the P. N. Lebedev Physics Institute (Physics Institute of the Academy of Sciences. Under his leadership in 1948 a radio astronomical base of the Physics Institute was created on the southern cost of the Crimea, near Simeiz. The Crimean base of the Physics Institute of the Academy of Sciences for a long time was the only powerful radio-astronomical observation station in the USSR and played a large role in development of Soviet experimental radio astronomy.

In the period from 1948-1951 the Physics Institute conducted extensive work on supplying the Crimean station with equipment and antennas. In these years the basic scientific work at the station was in the area of applied problems; properties of the ionosphere and troposphere were studied. A series of important radio astronomical investigations was also conducted. To this first of all we should relate results obtained by B. M. Chikhachev on the study of radio emission of active regions on the sun (1948-1949), connected with sunspots. Essentially this was the first work in experimental study of radio emission of the "perturbed" sun. At the Crimean station of the Physics Institute of the Academy of Sciences the first cliff radio interferometer in the Soviet Union was introduced, with the help of which important results were obtained on the refraction of radio emission in the earth's atmosphere, and also observations of discrete sources of radio emission were conducted. In these years the Crimean station conducted intense work on development of equipment and methods of investigation so necessary for radio astronomical experiments. As a result, at the beginning of the 1950's it became possible to cross completely to purely radio astronomical investigation of a very wide profile. From 1952 work at the station was conducted under the leadership of V. V. Vitkevich.

By this time Soviet radio astronomers were faced with the serious question about wide and systematic development of radio astronomical investigations, since radio astronomical methods of investigation have a huge value for astronomical science. The basic difficulty in this problem was the absence of powerful means of observations and cadres of radio astronomers. Up to the end of the 1950's radio astronomical technology was very weak in equipment. Observations were conducted mainly with the help of old modified radar stations; comparatively small, imperfect antenna systems were used. The break between experimental radio astronomy and optical astronomical investigations had also defined difficulty of growth.

One of the basic problems of experimental radio astronomy is the insufficient resolving power of the instruments. Angular resolving power φ of any instrument is determined by the

relationship $\varphi \sim \lambda/D$, where λ — wavelength of incident radiation, D — aperture of receiving device. Therefore as compared to optical astronomy radio astronomers must develop huge aerial units for the necessary resolution. Actually, for a resolution of one angular minute (which by no means is a record for classical astronomy) in the range of meter wavelengths antenna constructions several kilometers and more in size are necessary. Creation of similar aerial units is a matter of huge difficulty. It is necessary to solve a number of design problems and carry out the most complex construction and assembly works. The cost of such an instrument as a rule is calculated in the millions and tens of millions of rubles.

Furthermore, space radio emission is very weak. In order to receive it, separating it against the background of surrounding interferences, it is necessary to use the finest methods of contemporary radio engineering, use highly sensitive and stable receiving equipment. As a result, the radiotelescope is a very complex radio physics installation consisting of an antenna and receiving arrangement. Therefore in radio astronomy we are faced with the fact that, as a rule, the radiotelescope does not possess such universality as the simpler optical instruments. For every experimental problem it is necessary to develop if not a new antenna, a new radiotelescope receiver.

Basic problems of experimental radio astronomy could be solved at scientific institutions possessing highly skilled radiophysics cadres. One such was the P. N. Lebedev Institute of Physics of the Academy of Sciences USSR, and also the Scientific Research Institute of Radiophysics (NIRFI) in the city of Gor'kiy.

At the Crimean Station of the Physics Institute of the Academy of Sciences in the 1950's there was intense development of new methods of radio astronomical investigations. In 1951 V. V. V[illegible]kevich offered a very effective method of investigation of external layers of the solar corona by "radioscopy" of its strong discrete sources of radio emission. Every year in June the sun passes near the source

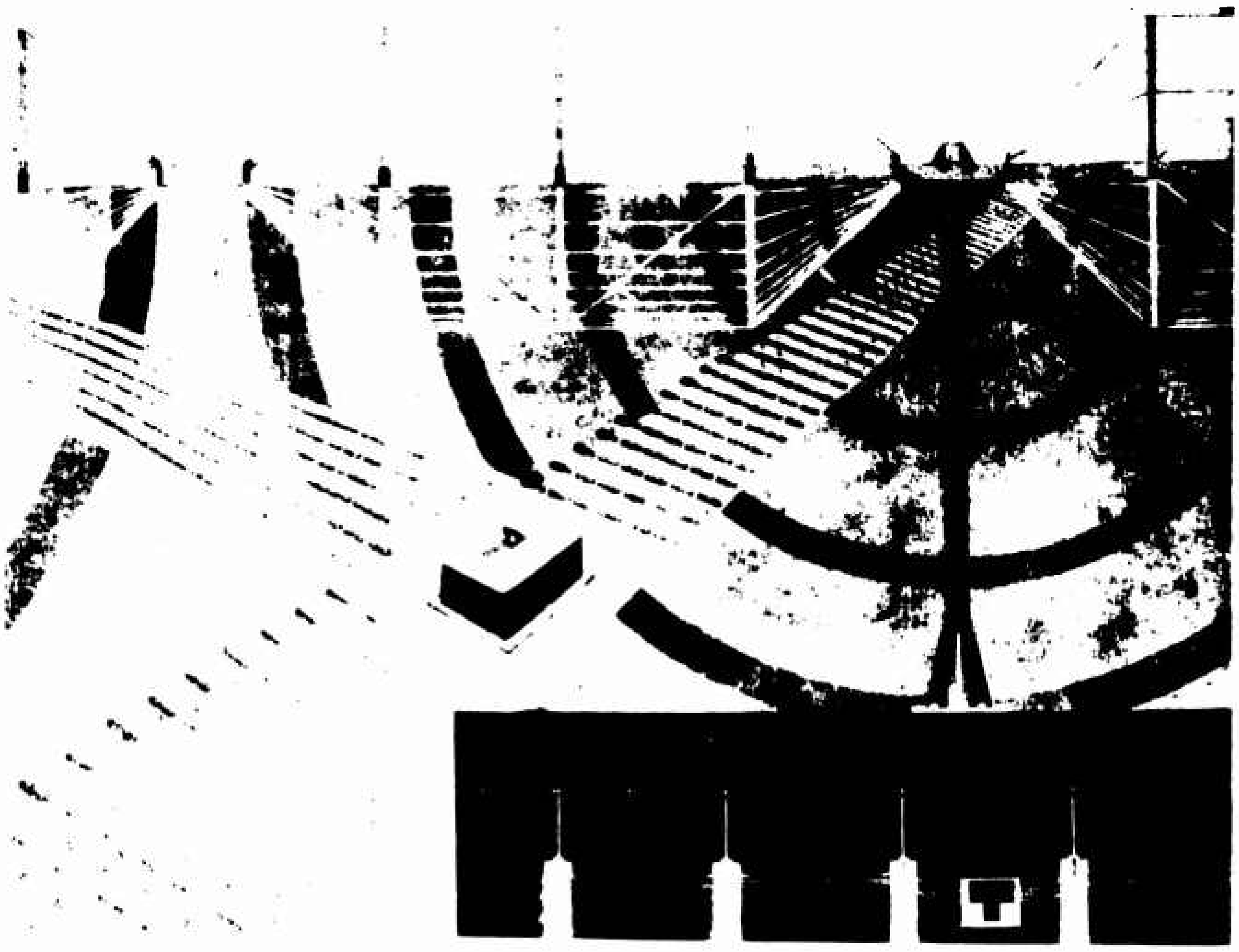
of radio emission Taurus A. Radio waves from the source disperse in the external layers of the solar atmosphere. By investigating the character of the scattering, one can determine parameters and physical properties of the most external layers of the corona. This method led to the discovery of the solar supercorona. At the Crimean Station of the Physics Institute of the Academy of Sciences in the 1950's much attention was allotted to the development of interference methods of observation. For the first time in the Soviet Union the distribution of radio brightness across the solar disk was investigated using a two-antenna interferometer, the methodology of spectral observations of the sun in a wide range of wavelengths was developed and an installation created for the observation of monochromatic radio emission of hydrogen on a wavelength of 21 cm.

In the city of Gor'kiy basic attention was allotted to the development of highly sensitive receiving radio astronomical equipment. The deep traditions of the Gor'kiy radiophysics school were expressed in this. Even in 1947 I. L. Bernshteyn created a modulation radiometer after the Dicke design on a wavelength of 10 cm — a receiving arrangement widely used in contemporary radio astronomy. In 1948 radiometers of meter range (on wavelengths of 1.5 and 4 m) were developed for observation of radio emission of the sun.

By the beginning of the 1950's finally a radio astronomy group was formed in the city of Gor'kiy, headed by V. S. Troitskiy, G. G. Getmantsev, M. M. Kobrin. Around 1952 the Gor'kiy radio astronomers started regular radio astronomical investigations.

The creation of large radio astronomical centers based at the radiophysics scientific research establishments was natural in view of the complexity of experimental problems. But this resulted in a break between the development of observation radio astronomy and astronomical investigations (also partly theoretical radio astronomy), leading in the largest astronomical centers of the Soviet Union. The necessity of removing this break meant that in the second half

Large Pulkovo radiotelescope (BPR).



Large radiotelescope UTR-2 (mock-up).

of the 1950's on one hand radio astronomical bases were begun at the largest observatories and, on the other hand, for work in radio astronomical departments at the radiophysics establishments astronomers were widely attracted, in the first place astrophysicists.

In 1953-1954 S. E. Khaykin created a department of radio astronomy at the Main Astronomical Observatory of the Academy of Sciences USSR (GAO AN SSSR, Pulkovo), which soon became one of the largest radio astronomical centers of the USSR.

Following the proposal of S. E. Khaykin at Pulkovo a new antenna array was developed, the so-called variable profile antenna (VPA). So far in radio astronomy basically two types of antenna arrays have been used: parabolic mirrors and interferometers of different complexity. The principle of the variable profile antenna is based on the fact that when a parabolic reflector is set up in a defined

direction actually only a certain "effective" part of its surface operates. Therefore it is possible to realize a system which models this working part of the surface of a parabolic mirror in the form of a strip and which can be built from separate flat elements — shields. The first similar effective system was constructed at Pulkovo in the form of an arrangement consisting of flat mobile reflecting shields. This is the large Pulkovo radiotelescope (BPR). Using this instrument, possessing a resolving power of up to several minutes of an arc in the centimeter range of wavelengths, a series of important observations was conducted. Regular observations on the BPR started in 1957.

In 1957 the largest observation radio astronomical base in the USSR began operation — the Serpukhov Station of the Physics Institute. Already in 1957 regular radio astronomical studies of the solar supercorona began here. In 1958 under leadership of A. Ye. Salomonovich (chief designer — P. D. Kalachev) at the Serpukhov Station of the Physics Institute of the Academy of Sciences was created one of the largest radiotelescopes in the Soviet Union — the 22-meter parabolic radiotelescope, with which most interesting observations of radio emission of the sun, moon, planets and discrete radiation sources were carried out.

In those same years the Serpukhov Station started work on construction of a large interference system — a cross-like radiotelescope 1 km × 1 km (director — V. V. Vitkevich). At present the first stage of this instrument — an "east-west" arm — has been completed and is being used for observations.

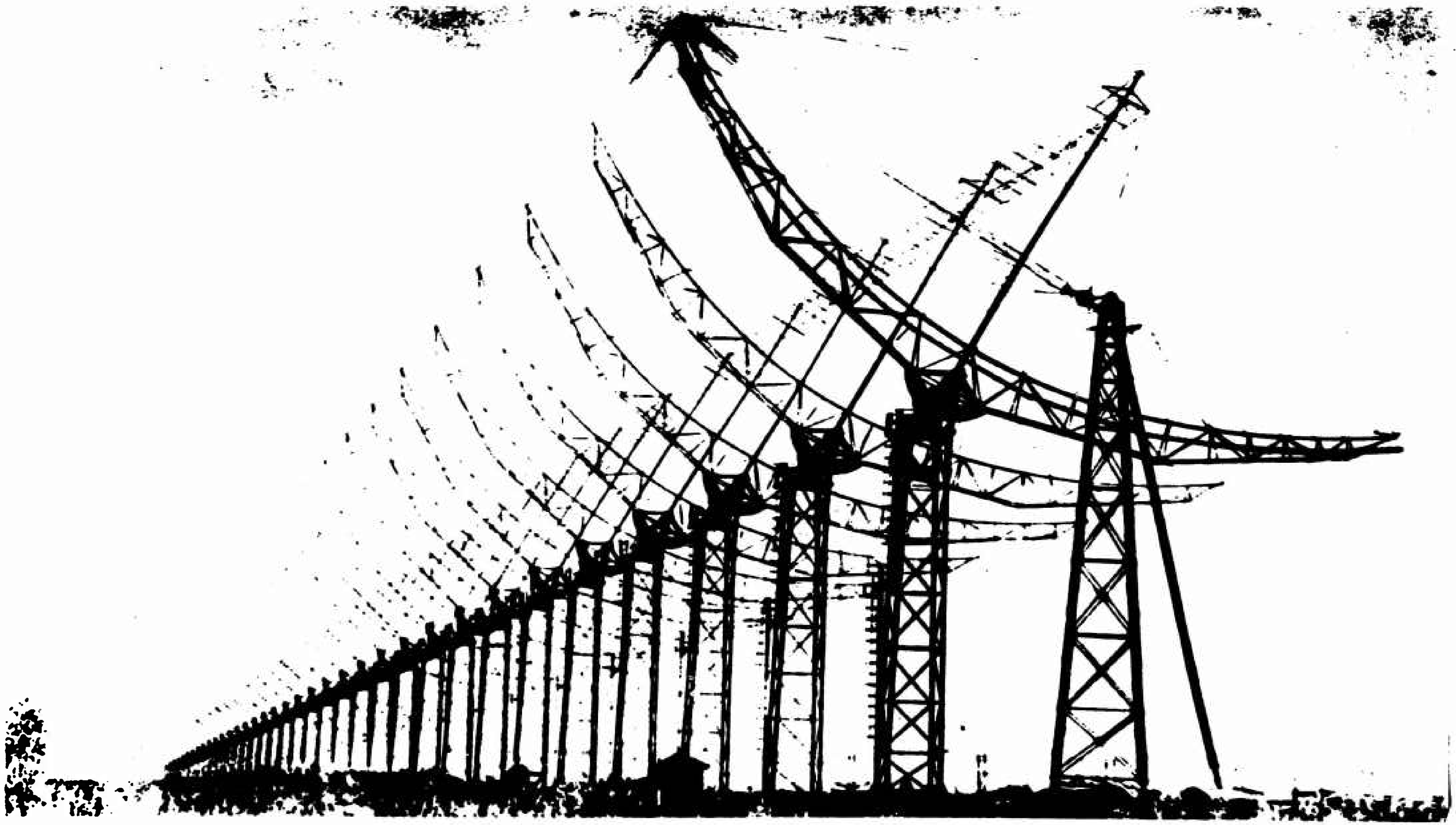
Thus, toward the end of the 1950's Soviet radio astronomy had several big observation bases with unique instruments. Naturally, in the period since the first experiments of the Brazilian expedition many valuable scientific results were obtained. The basic areas of radio astronomical studies were defined: study of radio emission of the sun, the circumsolar medium, moon and planets, discrete sources of radio emission, background of space radio emission. However, the difficulties connected with the small number of radiotelescopes remained. There was a lag in observation radio astronomy

as compared to such countries as the United States, England, Australia. At the same time in development of fundamental theoretical ideas and deep interpretation of obtained results, the Soviet radio astronomical school always held advanced positions in world science.

By the beginning of the 1960's it was clear that radio astronomy is a complex overall division of contemporary science and the problems of this field of knowledge can be solved only with closest collaboration of specialists — astrophysicists, radiophysicists, designers, and engineers.

In November 1961, the scientific council covering all of "Radio Astronomy," was created, which was responsible for leadership and coordination of research work in astronomy in the Soviet Union. Chairman of the Council was Acad. V. A. Kotel'nikov.

By the beginning of the 1960's the number of radio astronomical centers of the Soviet Union had increased. Along with the largest "old" bases of radio astronomy (Physics Institute of the Academy of Sciences, NIRFI, Main Astronomical Observatory) such radio astronomical stations as, for example, the base of the Institute of Physics and Electronics of the Academy of Sciences of the Ukrainian SSR (IRE Academy of Sciences of Ukrainian SSR, director — S. Ya. Braude) were created, where the interference radiotelescopes were introduced and put into service and a series of important studies in discrete sources of radio emission conducted. By now at IREAN Ukrainian SSR final adjustment has been made and parameters of the T-form radiotelescope UTR-1 with electrical beam pumping studied in detail. Construction of antennas for the large UTR-2 radiotelescope is finished. At the IRE Academy of Sciences of the Ukrainian SSR observations are being conducted in the range of decameter wavelengths (from 12.5 to 30 m). So far radio astronomical investigations have been conducted basically in the centimeter, decimeter and meter ranges of wavelengths. Radio astronomical work is being successfully conducted at the Byurakan Astrophysical



Cross-like radiotelescope of the Serpukhov Radio Astronomical Station FIAN.

Radiotelescope of Crimean Astrophysical Observatory of Academy of Sciences USSR. (Near Simeiz; controlled with help of an electronic computer.)

Observatory and at the Institute of Radio Physics and Electronics of the Academy of Sciences of the Armenian Soviet Socialist Republic (IRFE Academy of Sciences of Armenian SSR). Here the great two-image antenna system (BDA) project is being developed. In contrast to existing systems with mobile mirror, the main reflector of the new BDA radiotelescope, whose diameter is 100 m, will be stationary. Second, a small mirror (diameter near 8 m), located above the large mirror, will shift. Gathering radio waves reflected by the

reflector, it will direct them into the receiving arrangement. The special form of the little mirror completely removes distortions peculiar to spherical mirrors.

Radio astronomical centers have been created in the Latvian Soviet Socialist Republic; successfully investigations are conducted at IZMIRAN USSR, specializing in study of the connection of phenomena in the radio frequency band and geophysical activity. Investigations of radio emission of the sun are being developed in a number of radio astronomical sections of observatories. First it is necessary to note one of the "oldest" observatory departments of radio astronomy — at the Crimean Astrophysical Observatory. Finally, even newer regions of radio astronomy are being developed, which will be mentioned below.

For 20 years Soviet radio astronomers obtained huge amounts of material from observations in the main divisions of this branch and made fundamental theoretical conclusions. Inside radio astronomy itself appeared a clear differentation of different sections, each with its own specific character. Therefore a more concrete explanation of the sequence of obtained results of the development of ideas can be conducted only with respect to separate areas of this discipline.

Investigation of Radio Emission of the Sun and Circumsolar Space

The study of radio emission of the sun is connected with the first successes of Soviet theoretical and experimental radio astronomy, which already has been mentioned. This direction became the "classical" area of Soviet radio astronomy. Theoretical bases of the mechanism of the thermal component of radio emission, the so-called "calm" sun, developed by V. L. Ginzuburg and I. S. Shklovskiy, obtained confirmation subsequently. Radio emission of the "calm" sun was studied experimentally during the years which were to the past minimum of solar activity (1955-1957), by M. A. Ovsyankin and B. N. Panovkin, who obtained maps of the distribution of radio brightness across the disk of an undisturbed sun on waves of

decimeter range and stu[illegible] ularities of this distribution. On the basis of these data B. N. Panovkin in 1957 constructed a new nonisothermal model of the solar corona.

Great scientific and applied value belongs to investigation of the radio emission of a "perturbed" sun, connected with the appearance of active formations. Even in 1946 I. S. Shklovskiy advanced a hypothesis about the cause of radio emission of a "perturbed" sun, examining it as the result of plasma oscillations in the corona, appearing when corpuscular fluxes pass through it.

The hypothesis of I. S. Shklovskiy turned out to be very good. Further study of certain basic types, so-called "bursts," of solar radio emission showed that the mechanism of their radiation is connected with plasma oscillations of the coronal medium. The hypothesis of plasma oscillations to explain outbursts of solar radio emission was developed in detail in the work of V. V. Zheleznyakov and B. N. Gershman in the middle 1950's and then (basically by the work of V. V. Zheleznyakov) was turned into an orderly theory of one of the basic mechanisms of solar radio emission. Another important mechanism responsible for increased radio emission of the sun, examined first by V. L. Ginzburg and G. G. Getmantsev in 1951-1952, is the mechanism of radio emission of relativistic electrons in the magnetic fields of solar spots (magneto-bremsstrahlung mechanism of the generation of the slowly changing component of solar radio emission (1962). V. V. Zheleznyakov in the 1960's thoroughly studied conditions of propagation, generation and absorption of electromagnetic waves in the solar corona in reference to the theory of nonthermal radio emission of the sun. The fruit of years of work by Zheleznyakov was the basic monograph "Radio Emission of the Sun and Planets," appearing in 1964. In the area of theoretical study of solar radio emission Soviet science holds advanced positions.

Achievements of observational radio astronomy are more modest, although from 1950-1965 interesting results also were obtained. Even at the beginning of the 1950's at the Crimean Station of the

Physics Institute of the Academy of Sciences extensive material was obtained on comparatively short-term monochromatic ejections of increased solar radio emission ("peaks"). Subsequently with the appearance of the large radiotelescopes at the Crimean Station of the Physics Institute of the Academy of Sciences (and then also at the Serpukhov Station) two-dimensional distributions were obtained of the radio brightness over the disk of the perturbed sun on 3.2 and 10 cm wavelengths (V. V. Vitkevich, A. D. Kuz'min, A. Ye. Salomonovich, V. A. Udal'tsov, (1957) and 8 mm (A. Ye. Salomonovich, N. A. Amenitskiy, R. I. Noskov, 1958). The obtained "radio images" of the sun permitted study of the connection between regions of increased radio emission and optically active regions.

From the introduction of the large Pulkovo radiotelescope in the region of investigation of radio emission of the "perturbed" sun, the Pulkovo radio astronomers have worked actively. Specialization of work of the Pulkovo school passed into the region of investigation of phenomena in the centimeter range of wavelengths and polarization investigations. Even in 1953-1955 N. L. Kaydanovskiy, E. G. Mirzabekyan and S. E. Khaykin developed a highly sensitive polarization radiometer, making it possible to separate the polarizing component of solar radio emission. Observations of 1956-1958 showed that above the majority of big sun spots exist regions of increased polarized radio emission (G. B. Gel'freykh, D. V. Korol'kov, N. F. Ryzhkov, N. S. Sobolev). These regions are connected with dense and hot condensations, located above sunspots in the lower corona in the presence of a strong magnetic field.

At the Pulkovo Observatory in 1957-1960 bursts of radio emission in the centimeter range of wavelengths were also successfully investigated. Subsequently (1960-1963) at the observatory a number of instruments was created for polarization investigations of radio emission of the sun in the centimeter range of wavelengths and the theory of polarization radiometers was developed (G. B. Gel'freykh, D. V. Korol'kov). New series of observations definitized the angular dimensions of sources of increased radio emission, permitted measurement of the spectra of these regions.

Traditions of first Soviet observations of solar radio emission during an eclipse were continued, this time in the shortwave (centimeter and millimeter) range, in the work of A. P. Molchanov and his colleagues. Measurements conducted during the eclipses of 1958, 1961, and 1962 permitted obtaining important information about the structure of the solar chromosphere.

Valuable results about the distribution of radio brightness of the sun in the range of millimeter waves, and also about bursts of radio emission in this range were obtained by A. Ye. Salomonovich using the 22-meter radiotelescope at the Serpukhov Station of the Physics Institute of the Academy of Sciences (FIAN) at the beginning of the 1960's.

Regular, daily observations of solar radio emission are being conducted by such establishments of the Soviet Union as IZMIRAN (Institute of Terrestrial Magnetism, the Ionosphere and Radio Wave Propagation of the Academy of Sciences, USSR), NIRFI (Scientific Research Institute of Radiophysics (at the Gor'kiy State University imeni N. I. Lobachevskiy)), Latvian Astrophysical Observatory, Crimean Astrophysical Observatory, Leningrad State University, SibIZMIRAN (Siberian Institute of Terrestrial Magnetism, the Ionosphere and Radio Wave Propagation (Siberian Department of the Academy of Sciences, USSR)), Abastumani Astrophysical Observatory. At IZMIRAN (director — M. A. Mogilevskiy) and at the Crimean Observatory (A. B. Severnyy, I. G. Moiseyev) nonsteady radio emission of the sun is investigated in connection with manifestations of geophysical activity, which introduces an important contribution to the "sun-earth" problem. However, one should stress that in spite of the huge importance, these works have still not attained a sufficiently high level. There is not enough standard equipment, reliably effective in regular observations; there are only small cadres of observers.

The successes of Soviet radio astronomy in study of the most external layers of the solar atmosphere are obvious. As already was said, in 1951 V. V. Vitkevich using his own method of "radioscopy"

discovered the solar supercorona — the most rarefied layers of the corona, extended tens of radii from the surface of the sun. Somewhat later the same result was achieved by the English radio astronomer Hewish. In subsequent years V. V. Vitkevich obtained from observations data which allowed determination of parameters and structure of supercoronal layers, dynamics of development of the supercorona and the motion of substance in this medium. Observations of V. V. Vitkevich and Hewish in 1951-1955 showed that the supercorona has a nonuniform structure and that heterogeneities are stationary. On the basis of results of 1954-1955 characteristics of the dispersing medium were found. Further observations made it possible to establish the dependence of the size of the supercorona on the phase of the 11-year cycle of solar activity. According to observations of 1957-1958 (V. V. Vitkevich, B. N. Panovkin) it was established that heterogeneities of the supercorona have an extended shape. This testifies to radiality of magnetic fields of the solar supercorona. In 1964 V. V. Vitkevich offered a two-component model of the solar supercorona (diffuse component and component from radial heterogeneities). He studied also numerous dynamic phenomena in the supercorona of the sun. The work of V. V. Vitkevich on the supercorona is some of the most interesting in Soviet radio astronomy.

Research on Radio Emission of the Moon and Planets

The first radio astronomical investigations of radio emission of the moon were conducted in the Soviet Union at the beginning of the 1950's. In 1952 at NIRFI under V. S. Troitskiy the first observations with precision receiving equipment were begun. At the Crimean Station of the Physics Institute of the Academy of Sciences M. Turusbekov (1952-1953) determined the upper limit of change of radio temperature of the moon in the centimeter range of wavelengths. Subsequently work on study of the moon by radio astronomical methods was concentrated at three basic centers: FIAN SSSR (Physics Institute of the Academy of Sciences of the Soviet Socialist Republic, director — A. Ye. Salomonovich), NIRFI (director — V. S. Troitskiy), GAO AN SSSR (Main Astronomical

Observatory of the Academy of Sciences, USSR, (director — N. L. Kaydanovskiy).

At FIAN after the 22-meter radiotelescope system was installed toward the end of the 1950's two-dimensional distributions of the radio brightness of the moon 8 mm- and 2 cm-wavelengths were obtained and the change of luminance temperature of the surface of the moon depending upon lunar phase was studied.

The Main Astronomical Observatory in that same period conducted radio measurements employing a large resolving power on wavelengths in the centimeter range. Shift of the effective center of radio emission of the moon was established, determined as a variable component of lunar radio emission.

At NIRFI (V. S. Troitskiy, V. D. Krotikov, A. G. Kislyakov) a method of precision measurement of the intensity of lunar radio emission with an error of not more than 1-2% was developed and successfully used, founded on comparison of measured radiation with thermal radiation of an ideal black disk of known dimensions (method of the "artificial moon"). In 1965 this cycle of study was completed under the name "Development of Methods and Results of Radio Physical Investigations of the Upper Cover of the Moon." Results of investigations showed that the upper cover of the moon 4-8 m thick is formed by silicate rocks and is in a strongly porous state. On the surface of the layer the density of the substance is approximately half the average density of the moon, increasing at 3-4 cm by a factor of 1.5-2, and further slowly increasing to the end of the porous layer.

In the surface porous layer of the moon a temperature rise with depth by 2-5 degrees to a meter is revealed, which testifies to the presence of an internal heat flow close to the flow from the earth, and to the hot mineral resources of the moon. According to the Gor'kiy radio astronomers the porous layer is 6-10 m thick.

Measurements made on the 22-meter FIAN radiotelescope

(A. Ye. Salomonovich, B. Ya. Losovskiy, V. N. Koshchenko) made it possible to construct the "radio image" of the moon in the centimeter range, revealing systematic decrease of luminance temperature by the poles. Analysis of radio images permitted establishing the law of latitudinal distribution of temperatures and definitizing the value of electrical constants of the lunar surface.

At the end of the 1950's at GAO the linearly polarized component of the radio emission of the moon in the centimeter range of wavelengths was first revealed and investigated (N. L. Kaydanovskiy, V. N. Ikhsanov, N. S. Soboleva, V. Ya. Gol'nev). Research in radio emission of the planets was successfully developed in the USSR. And again the appearance of constructuve work is connected with large radiotelescopes being put into operation. A. D. Kuz'min and A. Ye. Salomonovich in 1959 measured the radio emission of Venus on 8 mm-wavelengths. The luminance temperature of the disk of Venus was determined and the change of radio temperature depending upon phase was studied. This work was continued during the inferior conjunctions of Venus in 1961 and 1962 on wavelengths of 0.5, 0.8, 3.3 and 9.6 cm. The average value of luminance temperature was determined, turning out to be of the order of 500-600°K. As a result it was possible to judge about the character of rotation of the planet and about presence on its surface of mainland sections. On the basis of spectral observations of 1962 one of first ionospheric models of the atmosphere of Venus was examined. In 1964 in the Physics Institute of the Academy of Sciences, USSR for the first time radio emission was measured of the planets Saturn and Mercury on a wavelength of 8 mm. In 1964 in the United States A. D. Kuz'min jointly with American radio astronomers conducted an investigation of polarized radio emission of Venus on a wavelength of 10.6 cm. The dielectric constant of the surface of the planet was determined and regions of lowered brightness were revealed, possibly the poles of the planet. It was convincingly shown that the surface of Venus is hot (temperature of equatorial part near 650°K).

In the Main Astronomical Observatory of Academy of Sciences, USSR Pulkovo radio astronomers in 1963-1964 conducted observations

of the radio emission of Jupiter, which showed that radiation belts of the planet on waves of centimeter range is considerably smaller than in the decimeter range, which indicates the location of more energetic particles nearer the surface of the planet.

In 1960-1963 V. V. Zheleznyakov successfully developed a theory of sporadic radio emission of Jupiter.

Radar Astronomy

During the last six years a new region of radio astronomy has been shaped — radar investigation of the planets of the solar system. N. D. Papaleksi's theoretical bases of radar study of the moon and planets was not wasted. Already in 1959 M. M. Kobrin (NIRFI) conducted a radar study of the moon on waves of centimeter range (3 and 10 cm). At present work in this direction is being conducted by the IRE Academy of Sciences, USSR under Acad. V. A. Kotel'nikov.

The first experiments in radar study of Venus were conducted in the United States in 1958-1959. However, as a subsequent check showed, they turned out to be failures. In April, 1961, the USSR, United States and England simultaneously carried out the first successful radar study of the surface of Venus. The distance to the surface of the planet was measured, and thus the value of the astronomical unit was definitized. Errors in measurement of distances during radar measurements are at least 100 times less than during the usual astronomical methods. In the middle of 1962 a radar study of the planet Mercury was conducted.

Finally, using the Soviet-created space radar a second radar study of Venus was conducted in 1962-1963. These experiments permitted measuring the distance to the nearest point of the surface of Venus with a standard deviation not exceeding 15 km. Measurements were made of the spectrum and energy distribution of a reflected signal depending upon the range of the reflecting zones. Comparison of these data permitted estimating the period of rotation of Venus and the direction of this rotation.

Vladimir Aleksandrovich
Kotel'nikov

In February, 1963, Soviet radar astronomy achieved a considerable new success. Radar study of the planet Mars was carried out at nearly 100 million kilometers. On the surface of Mars the presence of sufficiently even sections several kilometers in size was revealed. It was possible to measure the reflectivity of the planet's surface. Simultaneously a radar study of Mars was conducted in the United States.

In October, 1963, a radar study of the planet Jupiter was made at around 600 million kilometers. Data of this location permitted determining the surface reflectivity. Finally, in 1964 several radar studies were made of Venus. The accuracy of distance measurement considerably increased (standard deviation around 2 km).

Data obtained during a radar study of the planets are very significant. Besides a study of the physical properties of the planet surfaces and atmospheres the basic parameter of the solar

system — the astronomical unit — was definitized as well as the elements of planetary orbits, which has a huge value for the calculation of interplanetary flight routes.

Work on radar astronomy in the Soviet Union is valued. In 1964 Acad. V. A. Kotel'nikov and his colleagues were honored by the Lenin Prize for a successful cycle of work on radar study of the planets.

Galactic and Metagalactic Radio Astronomy

The problems of studying galactic and metagalactic noise are probably the most interesting from an astrophysical point of view. First of all, the most distant objects are studied, and radio astronomical methods have here a series of advantages as compared to optical methods. Furthermore, the data from radio astronomical observations can be connected with the solution to the most difficult problems of nature — explanation of the origin and evolution of galactic objects and external galaxies. On the other hand, the observation of such remote objects, reaching the limit of instrument sensitivity, presents special requirements to the receiving devices and a high antenna resolving power is needed.

Therefore it is clear that up to the last five to seven years, while Soviet radio astronomy experienced a sharp shortage in powerful observational technology, the successes of experimental galactic and metagalactic radio astronomy were small. At the same time in solving theoretical questions connected with the problems of cosmic radio emission, the leading role of Soviet science obtained full world acknowledgement. In this region the work of such prominent Soviet scientists as I. S. Shklovskiy and V. L. Ginzburg was the most fruitful.

Up to 1953 it was considered that nonthermal cosmic radio emission is formed in the atmospheres of stars ("radio stellar" hypothesis). This hypothesis was also held by Soviet astrophysicists. However the detection of a spherical component of nonthermal

galactic noise showed the lack of validity of this theory. The assumption was expressed that the cause of the "background" of cosmic radio emission is the bremsstrahlung of relativistic electrons in interstellar magnetic fields. The spectrum of this "synchrotron" cosmic radio emission depending upon the power spectrum of relativistic electrons was calculated. Certain works estimated different effects connected with synchrotron radiation of particles in the galaxy.

At present this theory (V. L. Ginzburg, I. S. Shklovskiy, G. G. Getmantsev, S. B. Pikel'ner, V. A. Razin and others) is conventional and fundamental for the study of physical processes in the galactic medium.

Subsequently the close connection of the problem of origin of the first cosmic rays and the nature of cosmic radio emission was revealed. V. L. Ginzburg showed that the relativistic electrons in the galaxy form the electron component of cosmic-ray primaries. The work of V. L. Ginzburg, I. S. Shklovskiy, S. I. Syrovatskiy, S. B. Pikel'ner in the 1950's was the basis for a new theory of the origin of cosmic rays, based on the data from radio astronomy. One of the fundamental problems of contemporary natural science was solved. These investigations subsequently were continued. In 1962 V. L. Ginzburg and S. I. Syrovatskiy showed that the concentration of cosmic rays in metagalactic space is essentially less than their concentration in the galaxy.

In the last twenty years Soviet theoreticians-radio astronomers developed the basis of the theory of cosmic radio emission, thoroughly analyzed the structure, composition and mechanism of radio emission of galactic and metagalactic objects. One should consider the almost full absence of data of Soviet experimental radio astronomy in those years.

I. S. Shklovskiy in 1952 showed the presence of a spherical component in the radio emission of our galaxy. This gigantic spherical system forms the so-called galactic corona. Detailed

theory of the galactic corona was developed by S. B. Pikel'ner and I. S. Shklovskiy in 1957. Subsequently this idea was widely developed in investigations of English, Austraillian and American radio astronomers. In 1953 I. S. Shklovskiy explained the mechanism of radio emission of a discrete source — remnants of 1054 Supernova (Crab Nebula) — using the synchrotron mechanism of radiation. He also developed the hypothesis that remnants of supernovae are the basic supplier of relativistic electrons in our galaxy. The character of the spectrum of optical radiation of the Crab Nebula was also explained. The considerable polarization of optical radiation of the Crab Nebula predicted on the basis of this theory was found at the end of 1953 by the Soviet astronomers V. A. Dombrovskiy and M. A. Vashakidze. The fundamentally new explanation of radiation of the Crab Nebula, laying wide paths for further investigations, was one of prominent achievements of astronomy of the last few decades. G. G. Getmantsev and V. A. Razin in 1954 developed detailed theory of polarization of the background of cosmic radio emission.

Study of monochromatic radio emission of the galaxy holds much scientific interest. The biggest role in astronomy belonged to study of the radiation of interstellar hydrogen on a wavelength of 21 cm. In 1945 the Dutch astrophysicist G. Van de Hulst predicted the theoretical possibility of radio frequency lines on a wavelength of 21 cm appearing in radiation. I. S. Shklovskiy in 1948 calculated the transition probability for this line and the expected intensity of monochromatic radio emission of the galaxy. In 1951 the radio frequency line of hydrogen was found by American, Australian and English radio astronomers. From 1948-1953 Shklovskiy developed in detail the basis for radio spectroscopy of the galaxy. In particular, he calculated the frequency and intensity of the hydroxyl radio frequency line OH(λ = 18 cm). In 1946 successful observations of this line were carried out in the United States, Australia and England.

As already was mentioned, experimental galactic and metagalactic radio astronomy in the 1950's took only the first steps in the

Soviet Union. In the work one should note the observations of discrete sources of radio emission in the centimeter range of wavelengths (N. L. Kaydanovskiy, N. S. Kardashev, V. M. Plechkov and V. A. Razin, 1954) and in the meter range (V. A. Sanamyan, V. V. Vitkevich and V. A. Udal'tsov, 1957-1958).

There was a break at the end of the 1950's. With the installation and operation of the large radiotelescopes intense investigation of cosmic radio emission began at the Physics Institute of the Academy of Sciences USSR, GAO AN SSSR, NIRFI, IRE Academy of Sciences of the Ukrainian SSR and at the Byurakan Astrophysical Observatory.

In 1959 Yu. N. Pariyskiy carried out observations of the galaxy on the great Pulkovo radiotelescope on wavelengths of 3.2 and 9.4 cm. As a result valuable scientific information was obtained about the structure of the central part of our stellar system. Pariyskiy developed a theory of the mechanism of radio emission of discrete sources in the center of the galaxy. This work was continued in 1960-1961 in a wide range of wavelengths up to 33 cm.

In these years important work was carried out on the composition of catalogs of discrete sources of radio emission. On the great Pulkovo radiotelescope positions and intensities of sources in the centimeter range were measured (Yu. N. Pariyskiy, 1960), at the Physics Institute of the Academy of Sciences the radio emission of 80 discrete sources was measured on wavelengths of 10 cm with the 22-meter radiotelescope (A. D. Kuz'min, 1961).

Important research in identification of a number of discrete sources with optical objects was conducted at the Byurakan Physics Observatory. Finally, in 1961 at IRE Academy of Sciences of the Ukrainian SSR work began on measurement of the spectra of intensities of discrete sources of radio emission in the "longwave" section of range (12-40 MHz).

Great successes have been achieved in recent years in the

study of monochromatic radio emission of the galaxy. In 1960 R. L. Sorochenko conducted the first study in the USSR on a wavelength of 21 cm. As a result a detailed picture was obtained of the structure of the galaxy in the region of the constallation Cygnus.

In 1963 colleagues of the Main Astronomical Observatory, Academy of Sciences, USSR and the Physics Institute of the Academy of Sciences located lines of excited hydrogen in the centimeter range in radio emission of bright nebulae. Calculation of frequency and intensity of the lines as early as 1958 had been done by N. S. Kardashev.

This discovery makes it possible to study the distribution and motion of regions of ionized hydrogen in both our and other galaxies.

As a result by the present time Soviet experimental radio astronomy has acquired extensive material in the study of space radio emission. In a short survey it is impossible even to enumerate all important work in this region conducted from 1960 to 1965. It is possible to note only the most essential moments.

In recent years Soviet scientists (I. S. Shklovskiy, Ya. B. Zel'dovich, V. L. Ginzburg, N. S. Kardashev and others) have been conducting theoretical analysis of quasi-stellar sources of radio emission.

On the basis of all observation data obtained by radio astronomical methods (in the 21 cm line and continuous spectrum), N. S. Kardashev, T. A. Lozinskaya and N. F. Sleptsova constructed a model of the spiral structure of the galaxy.

The Main Astronomical Observatory, Academy of Sciences, USSR, has been conducting studies of the fine structure and the central part of the galaxy using the OH line.

Catalogs of discrete sources are being compiled according

to observations made at NIRFI, GAO AN SSSR, FIAN SSSR, IRE AN USSR.

NIRFI has been conducting measurements of the intensity of cosmic radio emissions at 0.725 and 1.525 MHz using the artificial earth satellite "Elektron."

Work at the Byurakan Astrophysical Observatory and NIRFI is interesting also. Observations are being made of the secular variation of the flow of radio emission of the discrete source Cassiopeiae (an effect predicted even in the 1950's by I. S. Shklovskiy).

One should especially stress the extraordinarily important (for the development of galactic and metagalactic radio astronomy) work being done by the Department of Radio Astronomy of the P. K. Shternberg State Astronomical Institute (GAISh). Here under the directorship of I. S. Shklovskiy for the last few years valuable theoretical and experimental investigations have been conducted. Only during 1964-1965 did the Department of Radio Astronomy GAISh obtain the following data.

I. S. Shklovskiy developed a theory of analogy of quasi-stars and the Seyfert galaxies (see the section "Extragalactic Astronomy"). These investigations are of great value in solving the problem of evolution of the metagalaxy. It is possible that quasars constitute the nucleus of very remote galaxies, in a state of gravitational collapse. Shklovskiy also developed a theory of the spectra of quasars in the radio, infrared and optical regions of the spectrum. He examined also the mechanism of radiation of the Crab Nebula in the millimeter, infrared and X-ray ranges.

G. B. Sholomitskiy investigated the quasi-stellar source of radio emission STA-102 (quasar). This work was the impetus for subsequent research and investigation of quasars as a source of radio emission. V. I. Slysh experimentally and theoretically investigated the longwave spectrum of cosmic radio emission. G. S. Khromov studied in detail the radio emission of planetary nebulae.

Recently radio astronomy opened possibilities to a serious scientific approach to one more new and very interesting field of study — the existence of extraterrestrial civilizations. The problem of existence and development of a reasoning life in the universe is of utmost value. Radio astronomical methods of investigation in principle permit the detection of radio signals of artificial origin which can be received from the nearest galactic and metagalactic objects. A reflection of investigations in this area is the May, 1964, Byurakan All-Union Conference on problems of extraterrestrial civilizations, in which such prominent scientists as V. A. Ambartsumyan, Ya. B. Zel'dovich, V. A. Kotel'nikov, A. A. Pistol'kors, V. I. Siforov, S. E. Khaykin, I. S. Shklovskiy, N. S. Kardashev and others participated.

Soviet radio astronomers are investigating questions of the possibility of existence of extraterrestrial civilizations with different levels of development, possible methods of establishing communication with them, criterion of identification of artificial signals and methods of separating them from natural cosmic radio signals received by radiotelescopes.

Radio astronomy at present is one of the important branches of contemporary science. Data from radio astronomical investigations have a fundamental value from the point of view of mastering the basic regularities of the universe. The applied value of radio astronomy (prediction of geophysical activity, investigation of circumsolar space and others) is ever-increasing.

Soviet scientists are the authors of many original methods of radio astronomical investigations, and also methods of designing optimum antenna constructions.

The successes of Soviet theoretical radio astronomy are especially considerable. Many works of our theoreticians rightfully are considered classical. These must include studies of the mechanisms of solar radio emission, problem of the origin of

cosmic-ray primaries, study of the physical nature of discrete sources of radio emission, investigation of the synchrotron mechanism of cosmic radio emission.

STELLAR COSMOGONY

In 1692 Isaac Newton, answering the question of whether his law of universal attraction could explain the formation of stars, wrote:

"...If all matter in the universe were uniformly distributed in the stellar depths, if each particle were to have a natural attraction to every other and if, finally, the space in which this matter were dispersed were finite, then this strong attraction would cause all matter to rush to the matter in the internal parts of this space and, consequently, one great spherical mass would have to form. But if all matter were distributed in infinite space, it never could be united into one mass, but a certain part of it would form one mass, another part – another, so that from this an infinite number of great masses in the whole of this infinite would result. In just this way the sun and fixed stars would happen...[1]

Based on the idea of Newton, J. Jeans in 1902 proposed a mechanism of so-called gravitational instability of a medium in a field of gravitation. Examining the behavior of fluctuation in gravitational gas, Jeans showed that there exists a certain critical scale, or wavelength of instability, with which the gravitational

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[1]J. Jeans. The Universe Around Us. M.-L., State Technical Press, 1932, p. 237.

energy of the fluctuations becomes comparable with the internal energy of the gas. When scales exceed critical, gravitation dominates over the elasticity of gas; in other words, potential energy becomes larger than kinetic. Thus, the mechanism of gravitational instability results in an initially uniform medium breaking up into a series of clusters, serving as centers of gas condensation.

The work of Jeans had an especially important value, being essentially the first attempt at a strict mathematical analysis of the origin of stars. Research in gravitational instability was historically the first appearance of stellar-cosmogonic work in the Soviet Union (N. D. Moiseyev, N. R. Reyn, see the collection "Thirty years of astronomy in the USSR"). In spite of the consideration of only the celestial-mechanical side of phenomena (inevitable then because of the lack of actual data), the work of the Moscow school of cosmogonists played a great role, promoting mathematical purity and strictness in posing and solving cosmogonic problems.

Naturally, stellar cosmogony, based first on astronomical data, essentially depends on the state of the art of astronomy; development of cosmogony in considerable degree repeats the phase of development of astronomy as a whole. The astrophysical inclination in stellar and cosmogonic studies in our country appeared in the 1930's in connection with the development of both theoretical work and observations at different observatories in the Soviet Union. In the Crimea G. A. Shayn and his coworkers started spectroscopic observations of the stars on a telescope with mirror diameter of 1 m; at the P. K. Shternberg State Astronomical Institute in Moscow extensive research was carried out in stellar statistics and variable stars (S. N. Blazhko, P. P. Parenago, B. V. Kukarkin); at the V. P. Engelhardt Observatory (below Kazan) studies were conducted in nonsteady processes in close binaries (D. Ya. Martynov, V. A. Krat); finally, at Leningrad University extensive theoretical research was conducted in stellar physics, the physics of nebulae and stellar dynamics (V. A. Ambartsumyan, N. A. Kozyrev, V. V. Sobolev). This work created the basis for cosmogonic investigations.

Similar research was inspired by the conviction of the short (as compared to ordinary stars) lifetime of hot giants, estimated by their radiation and reserve of nuclear energy (see, for example, O. Struve, 1954). Ambartsumyan studied the age of stars, originating from considerations of stellar statistics (1937) and creating an orderly dynamic conception of the appearance of stars and stellar groups.

As it is known, in the environments of the sun binary and multiple stars compose approximately three quarters of the total number of stars. The ratio of the number of binary and multiple stars to the number of single stars is determined by interrelations between processes of formation of binaries during the gravitational interaction of single stars and inverse processes of the destruction of binaries. After a sufficient interval of time among these processes a certain statistic equilibrium should be established, characterized by a definite ratio of the number of binary stars to the number of single stars. As was clarified by V. A. Ambartsumyan (1937), the observed ratio of these numbers by many orders exceeds the expected equilibrium value. These considerations led V. A. Ambartsumyan to conclude that the age of stars in the galaxy is essentially less than the setup time of statistical equilibrium in it. This time, characterizing the age of the galaxy and being the upper limit of the age of stars, is around 10 billion years.

On the other hand, from analysis of the stability of open star clusters (V. A. Ambartsumyan, 1938) it is possible to deduce the time of existence of a given cluster, characterizing the decay time of the cluster as a result of the departure from it of stars with speeds exceeding parabolic. It turned out that for a cluster of Pleiades type with a mass several hundreds of solar masses the lifetime does not exceed a billion years; for a cluster with smaller mass — several tens of millions of years. Consequently, the age of individual clusters is less than the age of the galaxy.

Still more unstable are the so-called stellar associations — groupings of stars of definite, usually rather rare physical types

(V. A. Ambartsumyan, 1947, 1949). V. A. Ambartsumyan and B. Ye. Markaryan (1949) at the Byurakan Astrophysical Observatory first studied the so-called O-associations — rarefied groups of giant stars of high luminosity, spectral class O.

The concentration of O-stars in associations is so small that these stars cannot long be held in the volume of the association and must rapidly disperse in the common galactic field. The characteristic decay time of associations does not exceed several millions of years (and in certain cases turns out to be still shorter), which is a thousand times less than the age of the galaxy. Study of the properties of stellar associations brought V. A. Ambartsumyan (1947) to a fundamental conclusion that the "formation of stars continues in the galaxy at present" and that the "appearance of stars occurs as groups, associations."

Subsequently the idea of association was considerably expanded by the work of the observatories (Byurakan P. K. Shternberg State Astronomical Institute, Crimean, Abastumani and others). It developed that besides O-associations there exist also aggregates of variables of stars of a rare type — T Taurus, called by V. A. Ambartsumyan T-associations. O-stars are hot giants; star of the T Taurus type are cold dwarfs. If most cases these objects exist jointly, forming associations of mixed type (V. A. Ambartsumyan, 1949; P. N. Kholopov, 1950). Many associations are connected with complexes of diffuse matter in the form of light and dark nebulae.

Such, for example, is the famous association in Orion, studied in detail by P. P. Parenago (1954) on the basis of data about stellar magnitudes, indices of color, spectra and proper motions of almost 3000 stars. This association includes the famous Orion nebula, in the center in a condensation of a huge number of variables. As P. P. Parenago clarified, the Hertzsprung-Russel diagram (H-R) for stars in the region of this nebula has a very unusual form and absolutely dissimilar to analogous diagrams for dispersed clusters. Along with the usual upper part of the main sequence there is a considerable number of subgiants located above

the main sequence. This undoubtedly indicates that stars together with the nebula are young objects which formed in one place. Hundreds of variables observed in the Orion nebula are young.

The large role of diffuse nebulae in the appearance and evolution of stars was indicated also by G. A. Shayn. In his investigations at the Simeiz Observatory Shayn jointly with V. F. Gaze and S. B. Pikel'ner examined the extensive complex of problems related to diffuse nebulae.

In 1949 Shayn and Gaze started a systematic study of gaseous nebulae, using a greatly improved method (using a fast-lens camera with narrow-band filters). The extensive material of observations accumulated by them (G. A. Shayn, V. F. Gaze, 1951, 1951, 1952, 1955) permitted revealing a series of fundamental regularities characterizing the properties of a diffuse medium and its interconnection with stars. Thus, for example, during the study of mutual location in the sky of diffuse nebulae and groups of hot stars it was clarified that the distribution of hot stars and nebulae in considerable degree repeats (G. A. Shayn, V. F. Gaze, 1953). This circumstance permitted the researchers to make an extraordinarily important conclusion concerning the genetic connection of hot stars and nebulae. The masses of nebulae in separate cases can reach very great values – hundreds and thousands of solar masses (G. A. Shayn, V. F. Gaze, 1952), whereas the general mass of the stars connected with the nebulae is much less. Analogous facts were revealed by G. A. Shayn and V. F. Gaze (1952) during an investigation of diffuse nebulae in other galaxies – M 31, M 33 and M 101. The large mass of the gas-dust component leads to the conclusion that gas plays a dominating role in these complexes.

The following important step in clarification of interrelations between diffuse matter and stars was made by V. G. Fesenkov and D. A. Rozhkovskiy (1952), using excellent photographs of diffuse nebulae obtained at the Alma-Ata Observatory using a fast-lens Maksutov telescope of Soviet production. Attentive examination of the original negatives showed that in diffuse nebulae an extraordinarily widespread phenomenon is the filamentary structure. In

certain cases the filaments will be differentiated into separate condensations, very visible in rays of the red H_α hydrogen line. It is possible to note, furthermore, clearly expressed star-chains or path, also connected with the filaments. These facts led Fesenkov and Rozhkovskiy to hypothesize that in this case the disintegration of gas-dust filaments into separate condensations, transformed later into stars, is observed.

Results of various investigations of Soviet scientists were at the May, 1952, conferences on questions of stellar cosmogony (see "Transactions of the Second Conference on Questions of Cosmogony." M., 1953). At these conferences A. I. Lebedinskiy and L. E. Gurevich presented an extensive theoretical conception of the gravitational condensation of diffuse matter, touching on different sides of the origin and evolution of stars and stellar systems and in many points anticipating investigation in this direction abroad.

Thus, A. I. Lebedinskiy noted that in examining instability jointly with the criterion of Jeans, which is the criterion of purely mechanical equilibrium, it is necessary to examine another criterion, considering the thermodynamic history of the gravitational cloud. This circumstance permits studying the compression of gas starting from the early stage of evolution of the galaxy.

Gurevich (1954) examined the effect on gravitational condensation by rotation and the magnetic field of compressing diffuse substance. An initially weak magnetic field is strengthened during compression and may cause effects observed in so-called magnetic stars.

A. B. Severnyy (1953) studied the stability of gas in a field of natural gravitation and in an external magnetic field. He showed that the magnetic field causes essential anisotropy of the stability of gas, that in turn leads to the accumulation of matter along force lines. Possibly this effect is connected with the formation of filamentary nebulae.

At the conference important questions on the balance of diffuse substance in the galaxy were examined also. Even in 1931 B. A. Vorontsov-Vel'yaminov (1931) during the analysis of the spectra of nonstationary stars ("new" Wolf-Rayet), and also planetary nebulae arrived at the idea that these objects can be suppliers of a considerable quantity of diffuse substance. Thus, a definite part of the interstellar medium can be the product of outflow from stars. At the conference B. A. Vorontsov-Vel'yaminov, A. I. Lebedinskiy and L. E. Gurevich noted that along with this diffuse medium there can be the material from which stars are formed. According to opinions in the galaxy there exists a definite balance of diffuse substance (condensed in stars and ejected by nonstationary stars) — regulating the rate of star formation. While there is diffuse substance in the galaxy, the formation of stars occurs.

The evolution of the galaxy is intimately connected with the evolution of separate subsystems of stars making up the galaxy. The idea about separation of stars into two different types of population was first advanced by V. Baade in 1944. As a result of study of the distribution of variables in the galaxy, B. V. Kukarkin in a work published in 1949 showed that this separation carries a more complex character. He established that there exist flat (type I, according to Baade), spherical (type II), and also intermediate subsystems (see the section "Formation of the Galaxies"). For example, the flat subsystems include the O-stars, gaseous nebulae, dispersed clusters, T Taurus-type stars and others; intermediate — novae, planetary nebulae; spherical — globular clusters and variables of type RR Lyrae. As Kukarkin noted, stars of different subsystems have various physical characteristics, paths of development and age.

Thus at the beginning of the 1950's as a result of the intense work of Soviet astronomers, often with rather modest means of observation, considerable successes were achieved in gaining knowledge of the basic regularities of the development of cosmic matter. It was definitely established that the formation of stars in the galaxy is still going on while the formation carries chiefly a group

character (associations, clusters and multiple stars). The unusual character of the H-R diagrams in the Orion association was clarified as being connected with diffuse matter, which permitted talking about the youth of this formation. The genetic connection of diffuse nebulae with hot stars and the importance of the role played by diffuse nebulae in the common balance of diffuse substance in the galaxy has been established. Concrete details of the mechanism of transformation of diffuse substance in stars were proposed, both observational(filaments and chains), and theoretical (consideration of the thermal balance of condensation, calculation of rotation and magnetic field). Finally, the ideas of different subsystems and their role in the general evolution of the galaxy were definitized.

At the same time a series of problems still awaiting solution was formulated, among them the central problem of properties of primary material from which stars are formed in the galaxy. To counterbalance the traditional point of view on the origin of the stars by the condensation of diffuse matter V. A. Ambartsumyan, relying on his idea about the dynamic instability of stellar associations, affirmed the possibility of stars from superdense bodies of comparatively small dimensions — protostars, forming, when they divide, the observed stellar groups and nebulae.

In subsequent years the concept of V. A. Ambartsumyan was essentially expanded thanks to new data, especially from extragalactic astronomy.

Thus, for example, V. A. Ambartsumyan (1956) noted that among multiple galaxies not less than half compose multiple systems of Trapezium type, which are, similarly multiple stars of the Trapezium of Orion type, unstable formations. A certain part of the multiple galaxies of such type has positive total energy and, consequently, is in the process of disintegration.

Starting from 1957 V. A. Ambartsumyan stresses the importance of the cosmogonic role of the nuclei of galaxies. Study of nonsteady

phenomena in nuclei led Ambartsumyan to conclude that "in nature can occur processes of ejections from nuclei of galaxies of relatively small masses. These ejected masses can in certain periods turn into conglomerates consisting of young nonsteady stars, interstellar gas and clouds of high energy particles" (Ambartsumyan, 1958).

The end of the 1950's and beginning of the 1960's in astronomy both in our country and abroad are characterized by stormy blossoming of astrophysics and on the basis of it — cosmogony. Progress in astrophysics was considerably promoted by new methods of investigation, especially in two regions directly connected with cosmogony: in the study of physics of interstellar matter and the evolution of stars.

Successes of the physics of interstellar matter in decisive degree are connected with the appearance and development of a fundamentally new method of obtaining astronomical information — radio astronomy. As it is known, interstellar matter is practically transparent to radio emission, which makes the radio method extraordinarily effective during the analysis of the structure of our galaxy, especially in its equatorial plane, containing the basic mass of gas and dust. A combination of optical and radio methods permits obtaining important information about the character of distribution of interstellar substance in the spiral branches of the Milky Way — the same place where young stars are encountered (O- and T-associations, dispersed clusters, etc.).

V. Hiltner (1949), J. Hall (1949) and Soviet astronomer V. A. Dombrovskiy (1950) found that the light of certain stars is polarized. Theoretical calculation of this phenomenon was carried out by G. Van de Hulst (1950), who showed that polarization of light can be explained by scattering on extended particles oriented by magnetic field. In 1953 Ch. Chandrasekar and E. Fermi examined a model of the spiral branch of the galaxy, supported in equilibrium against the forces of attraction of the magnetic field. This

problem from the observational point of view was analyzed by G. A. Shayn (1955), who compared data on polarization of the light of stars in the plane of the galaxy with distribution of elongated diffuse nebulae. G. A. Shayn concluded that the movement of gas in nebulae is controlled by the magnetic field. Analogous results were obtained by B. A. Vorontsov-Vel'yaminov (1955) during the study of behavior of diffuse matter in other galaxies. In these conditions the concentration of young objects in spiral branches inevitably leads to the conclusion that they appeared from a diffuse medium, inasmuch as only the latter is held in spirals by magnetic forces. The massive objects which appear — stars — no longer are controlled by the magnetic field and gradually disperse in the galactic disk (S. B. Pikel'ner, 1962).

Another complex of cosmogonic problems is connected with construction, structural peculiarities and evolution of diffuse nebulae. In 1938 B. Stremgren, studying the physical state of interstellar hydrogen, concluded that around stars of early spectral types (O — B2) hydrogen should be ionized, and far from these stars it is neutral (zones HII and HI). A. I. Lebedinskiy (1953), and also J. Oort and L. Spitzer (1955) showed that the pressure of hot ionized gas should lead to its expansion. An analogous idea about the instability and disintegration of diffuse nebulae was reached also by G. A. Shayn and V. F. Gaze during an analysis of extensive material from observation, which they obtained at the Simeiz Observatory. Optical data and theoretical forecasts were confirmed by radio astronomical observations; thus, for example, the expansion of gas around the Orion nebula and others was found.

Ideas about the interaction of ionizing radiation with neutral gas permitted clarifying a number of structural details observed in diffuse nebulae — emission fringes, inclusions of dark matter in the form of gulfs, globules, etc. Globules, discovered in 1947 by B. Bok and E. Reilly (1947) are usually considered to be the ancestors of stars, allowing the possibility of their gradual condensation under the effect of gravity. Such a process for an isolated gaseous dust globule calculated by E. L. Ruskol (1955).

In 1953 A. I. Lebedinskiy and in 1955 B. Bok noticed that globules in diffuse nebulae must be intensively compressed by the surrounding hot gas. This possibility was confirmed by gas-dynamic calculations (E. A. Dibay, S. A. Kaplan, 1964).

Globules are closely connected with the so-called comet-shaped nebulae, long attracting the attention of observers by their unusual forms. Interest toward these objects was especially revived after the work of V. A. Ambartsumyan (1955) showing that comet-shaped nebulae as a rule are connected with nonstationary stars of the type T Taurus, whose youth has been established from a number of independent considerations. Subsequently E. A. Dibay (1960, 1963) assumed that comet-like nebulae are the end product of the evolution of dark matter in the form of globules and gulfs after one or several young stars of the type of T Taurus appear in them. An essential part of this process is the focusing of shock waves appearing on the boundary between neutral and ionized gas, which leads to strong compression of the neutral gas.

In 1954 G. Herbig (1954) and G. Haro found on photographs of the Orion nebula, taken several years apart, the appearance of star-shaped objects, invisible on preceding photographs. These so-called Herbig-Haro objects are apparently still younger objects than stars of the T Taurus type. In such a case the stage of the Herbig-Haro objects can directly follow process of gravitational condensation.

All the above problems concern star formation during the last several million years in flat subsystems of the galaxy (population of type I). The question about conditions of star formation on early stages of evolution of the galaxy is natural, i.e., about the appearance of older stars, observed now in spherical subsystems (population II). To answer this question it is necessary to examine the evolution of stars of spherical subsystems.

In theoretical astrophysics the method of constructing so-called models of stars is well-known, occurring in the study of distribution

in a star of the basic parameters — density, temperature, coefficient of absorption, chemical composition, etc., derived on the basis of known physical laws. By assigning definite assumptions about the mechanism of nuclear reactions in the mineral resources of a star, it is possible to study the change of stellar structure in time, i.e., to study the stellar evolution. It is clear that in connection with the extraordinary complexity of the problem a similar procedure is connected with a huge volume of calculating work. The essential progress attained in this region during the last few years is connected both with improvement of information about nuclear reactions and with the development of machine methods of calculating stellar models (M. Schwartzchild, 1961). In the Soviet Union at present the calculations of stellar models occupy A. G. Masevich, D. A. Frank-Kamenetskiy (1959) and others.

An attempt to construct evolutionary models to explain the observed H-R diagrams was made by F. Hoyle and M. Schwartzchild (1955). They examined also the evolution of the giants of flat subsystems, distinguished from stars of a spherical component by other contents of heavy elements in relation to hydrogen. Comparison of calculation results with extensive observational investigations of the diagrams of spherical and dispersed accumulations — conducted in 1951-1957 by number of foreign astronomers including H. Arp, A. Sandage, W. Baum and others (see "Orion and Evolution of Stars," 1962) — permitted bringing into a single system the various properties of stars of different populations of the galaxy. Distinctions in chemical composition, evolutionary paths of stars on the H-R diagram and in their space distribution turned out to be possible to present within the bounds of a single diagram, satisfactorily explaining the basic observed facts.

Thus, toward the end of the 1950's as a result of the accumulation of an extensive totality of observational data and intense theoretical research in our country and abroad an orderly system of views on the basic problems of origin and evolution of the galaxy was formed. A decisive factor was the appearance of new methods of investigation, which made it possible to unite the most

various problems into one whole. As already was noted, the development of physics of the interstellar medium promoted the use of radio astronomical methods from the observational side, and also the methods of gas- and magnetohydrodynamics from the theoretical side. An analogous picture is observed in investigations connected with the evolution of stars. Theoretical calculations of the evolution of stellar models has been promoted by computer technology, whereas progress in analysis of the H-R diagram for spherical and disperse clusters is significantly connected with the introduction of precision photoelectrical technology.

The picture described below of evolution of the galaxy is the result of the efforts of a great number of researchers both in our country and abroad. The data from observations, especially concerning the H-R diagrams, basically were obtained abroad. Together with that the attentive reader can note that a number of cosmogonic ideas was formulated earlier in the Soviet Union.

According to existing opinions (S. A. Kaplan, S. B. Pikel'ner, 1963), on early stage of evolution of the galaxy it can be represented in the form of a rarefied cloud of gas in the process of gravitational condensation. The progress of condensation, mass and size of parts into which the initial system disintegrates, as F. Hoyle (1958) and L. M. Ozernoy (1962) proved, depend on the thermal balance of the condensing cloud. If gravitational compression occurs faster than cooling, the system is compressed as a whole, otherwise gas is supercooled and separates into parts. What has been said pertains also to fission products; thus, fragmentation carries a step-wise character, leading to separation of the galaxy into globular clusters, and globular clusters — into stars.

The spherical system thus formed (first generation stars) corresponds to old objects of the globular cluster type. Massive stars pass the supernovae stage, ejecting gas enriched with heavy elements as a result of nuclear reactions. Due to rotation of the galaxy this gas with remnants of the initial gas concentrates ever more in the galaxtic plane. Second generation stars appearing in

this region (stars of flat subsystems) form in a medium with greater content of heavy elements than in the initial medium. During every such cycle part of the gas is irreversibly expended on the formation of stars with small mass (their evolution time is great), thus leaving the "game." The process of star formation continues in the galaxy as long as gas is in it. This is confirmed by observations of other extragalactic objects, showing continuous change of the ratio of gas mass to the total mass of the galaxy. This ratio is greatest for irregular and Sc-galaxies with a great quantity of diffuse nebulae, hot stars, etc.; in elliptic galaxies, in which the process of star formation has practically finished, there is no gas.

As can be seen, the essential point of this concept is the interconnection of the origin of separate stars with the general problem of origin and development of the galaxy. This circumstance is typical for contemporary cosmogony, characterized by the extraordinarily wide scope of the most various problems. Such a position is the natural result of interrelations of cosmogony with different astronomical and physical disciplines. If at the beginning of the century cosmogony was more or less passively satisfied by data obtained in different areas of science, then at present the theoretical calculation and setting up of a number of astrophysical observations ever more frequently are planned proceeding from cosmogonic considerations. Ideas of evolution literally pierce astrophysics. Such a wide development of cosmogony using methods and results of the most various branches of physics is closely connected with process of interpenetration and integration of natural sciences, characteristic for the second half of the XXth Century.

Which are the directions of development of contemporary astrophysics that will show the most interesting cosmogonic results? First of all, extragalactic astronomy with two basic directions: the spiral structure and the nuclei of galaxies. From the first we can expect essential progress with the fundamental idea of the origin of spiral branches, and in multiple galaxies — of crosspieces, intergalactic bridges, etc., as a result of condensation of diffuse

matter in the presence of a magnetic field (B. A. Vorontsov-Vel'yaminov, 1959, 1964; S. B. Pikel'ner, 1965). The second direction is connected with study of nonstationary nuclei of galaxies and objects of the same type as quasi-stellar sources of radio emission, the discovery of which can boldly be called the central event of astronomy in the XXth Century. We must note that considering all the singularity of properties of these objects, their appearance in science was to a certain degree prepared by the development of a series of astrophysical considerations, in the first place the concept of V. A. Ambartsumyan of superdense bodies and successes in the physics of radio galaxies (I. S. Shklovskiy, 1962).

Extragalactic astronomy is presently burgeoning to such a degree that to make any prediction, except a general mention of the enumerated problems, is impossible. At the same time it is clear that successes in the field of study of the physics and evolution of the galaxies unconditionally will promote deeper understanding of stellar-cosmogonic problems.

DEVELOPMENT OF PLANETARY COSMOGONY

Fifth years ago planetary cosmogony throughout the world strongly differed from what it is now, both in the character of approach to the problems facing it and in its role among the other sciences. Up to the middle of the century hypotheses about the origin of the solar system were advanced basically in order to satisfy the natural curiosity of man – his tendency to learn how that system of celestial bodies was formed of which our earth is a member. Attempts to answer this question relied on a narrow circle of actual data – chiefly on the main mechanical regularities of the structure of the planetary system. Some hypotheses carried a qualitative character, giving only a description of the assumed process of formation of the solar system; others contained besides a qualitative picture mathematical analysis of certain simplified models and schemes, used approximately to depict separate stages of the evolution of bodies. Often the complexity of this analysis had a hypnotic effect and camouflaged both the imperfect agreement of scheme and reality and the presence of other stages of development, never subjected to mathematical investigation.

The transition to the contemporary stage of development of planetary cosmogony, beginning in the 1940's and ending in the 1950's, consisted not only in rejecting the long-dominant idea of the formation of planets from incandescent gas clusters, but also the practically general acceptance of the idea of a cold initial state of the earth. It appeared also in wide realization of the

importance of a true presentation about the origin of the earth and planets for correct understanding of their present structure and state. This increased the interest toward planetary cosmogony of the specialists in earth sciences. At the same time the abundance of actual data about the earth, which along with astronomical data must serve as a basis and criterion of practice during the development and check of cosmogonic hypotheses and theories, strengthened the interest of astronomers toward sciences about the earth.

Requirements on the hypotheses and theories in planetary cosmogony colossally increased: besides a serious foundation of main ideas, now at least a qualitative explanation of the large amount of actual information is required — from astronomical to physicochemical. The range of questions embraced by planetary cosmogony was expanded. The course of investigations strengthened the understanding that all small bodies of solar system — not only the asteroids, but also the comets — appeared in single process together with the formation of the planets. Regarding, however, meteorites, when it was established that they are members of the solar system and do not arrive from interstellar space, and the possibility of their comprehensive laboratory analysis, meteorites became the most important source of information about the chemical, physicochemical and nuclear processes which occurred in planetary substance (see p. 153).

Wide use in contemporary planetary cosmogony of data and methods of physics and chemistry led to new approaches to the problem: if earlier the basic features of formation of the planets were clarified by the analysis of mechanical regularities of the solar system and only then was discussed the possibility of explaining by this process also physical and chemical data then now investigations appeared in which the basic features of the cosmogonic process are established from analysis of physicochemical or even nuclear processes occurring in the earliest stages of formation of the solar system.

Such was, in the most general points, the development of world planetary cosmogony during the last half century. That was

the surroundings against the background of which Soviet planetary cosmogony developed.

Soviet planetary cosmogony could rely in its development on past materialistic traditions of Russian sciences, which had grown up by the time of M. V. Lomonosov. But concrete cosmogonic investigations in prerevolutionary Russia were very few. In this period only individual particular questions were investigated.

In 1871 F. A. Bredikhin dedicated one of his popular articles to "Past and Present of Bodies of the Solar System, Chiefly the Earth." Although he started from ideas conventional at that time about the heated initial state of the earth, he brought in numerous arguments indicating a solid state of the greater part of terrestrial mineral resources, and expressed original ideas about the origin of the contemporary internal heat of the earth. Later, in 1893, already an academician, F. A. Bredikhin addressed the Academy of Sciences with the speech "Physical Changes in Celestial Bodies," in which he stressed the exceptional value of studying the changes occurring in celestial bodies. In 1877 D. I. Mendeleyev, relying on his own investigations of the liquefaction of gases and proceeding from the cosmogonic hypothesis of Laplace, analyzed the cooling of a heated gas cluster and concluded that even on this stage an iron nucleus had to form for the earth. At the beginning of the XXth Century the mathematician A. M. Lyapunov in a series of remarkable memoirs investigated the figures of equilibrium of revolving liquid bodies and refuted the conclusions of the English mathematician Darwin, assumed the latter as the basis of the hypothesis about separation of the moon from the earth (the works of A. M. Lyapunov were completely published only in the 1920's).

After the October Revolution the first hypothesis in Russia about the origin of the solar system was advanced by V. G. Fesenkov — an astronomer, who still, even after almost 50 years, continues his work in planetary cosmogony. In 1918-1919 he proposed his vortex hypothesis, which was an attempt to modify the Laplacean hypothesis. The picture sketched by V. G. Fesenkov was as follows:

when a revolving nebula is compressed, its mineral resources are heated, but nonuniformly, and therefore convective flows appear. On the interface of the approach flows undulations start, changing then into vortexes. Drawing in the surrounding substance, these vortexes, fading away, leave the place where they condensed. The stability of the condensation with respect to the tidal forces created by the attraction to the center of the nebula rapidly increases with distance from the center. Therefore a stable condensation will be formed in the surface layers of a nebula near the equatorial plane. This is the conception of planets. In the compression of a nebula separate condensations will be formed through large intervals of time, and therefore the orbits of the planets are located great distances from each other.

The Laplace nebula had to possess very fast rotation so that on the equator the centrifugal force could exceed gravitation. It remained incomprehensible why the present sun revolves slowly. Besenkov believed that the rotation of a nebula could be incomparably slower — it was necessary only for a nebula to be flattened, and thanks to this stable condensations were formed near the equatorial plane, ensuring thereby small slopes of the planetary orbits.

However, even in the hypothesis of V. G. Fesenkov it remained unclear how the sun, possessing 99.8% of the total mass of the solar system, required at the same time only 1-2% of the total angular momentum.

Ten years after V. G. Fesenkov (1930) rejected his vortex hypothesis. The basic cause was that data on the age of the sun and the earth contradicted the assumption that the planets were formed prior to the final formation of the sun. (It is necessary, however, to note that at that time information about the age of these bodies was very imprecise.) Furthermore, it was "extremely difficult to judge if in the state convective currents and the swirl flows appearing as a result deliver condensations of the necessary initial density."

By then a conspicuous place in cosmogony was occupied by the Jeans-Jeffreys hypothesis about separation of planets from the sun under the impact of external forces. V. G. Fesenkov noted weak sides of this hypothesis, but nonetheless was forced to accept it. He wrote: "another way out, however, is lacking, and this hypothesis should be considered as corresponding the closest to contemporary the state of astrophysics."

At the end of the 1920's in the theoretical department of the State Astrophysical Institute a group of mathematicians and students of celestial mechanics formed (G. N. Duboshin, N. D. Moiseyev, N. F. Reyn, V. V. Stepanov, B. M. Shchigolev), making up in 1931 the department of cosmogony and celestial mechanics of the State Astronomical Institute imeni P. K. Shternberg. The basic problem they set themselves was: "Revision and reconstruction of cosmogonic theories with the purpose of making cosmogony a scientific discipline." They broke down this problem into the following three phases.

1. Inspection of the most outstanding cosmogonic theories of particular value for a "healthy nucleus," i.e., those conclusions which are strictly grounded. A fight was conducted "the so-called pure patterns of the individual problems studied by the separate cosmogonic theories. In other words, the aim was a clear and distinct formulation of all those simplified assumptions which an author introduced into his own theory and the presence of which permitted him to conduct mathematical analysis of the evolution of a considered system of celestial bodies. The purpose of the fight was to show all those simplified schemes with which cosmogony actually deals, however hazy general and shadowy is the individual cosmogonist in expressing his formulation of problem" (N. D. Moiseyev, 1941).

2. Comparison of results of cosmogonic theories subjected to inspection with available empirical information. For this it was considered necessary to separate from the data of observations those which "have evolutionary origin and only those which can have significance for the cosmogonist." (This not very successful

formulation concealed the fact that empirical data in the first place of statistical character, frequently are distorted by observational selection, whereas for comparison with cosmogonic theory it is necessary to know the true characteristics of the examined system of celestial bodies.)

3. Reconstruction of cosmogonic theories on the basis of results of the first two phases of investigation.

Compilers of this program were participants in a seminar on qualitative theory of differential equations, and this produced the fundamental aim that "in cosmogonic problems the most essential and characteristic is not the quantitative side of a phenomenon, calculated on small intervals of time, but the qualitative nature of the process, characterizing it during very large intervals of time," and therefore one should study the "general qualitative characteristics of evolution of the examined celestial bodies."

In fact real bodies only a finite interval of time are under conditions close to some pure scheme, and therefore without quantitative appraisals of the speed of the evolutionary process it is impossible to establish whether a given interval of time can be considered very (or even infinitely) large. Nonetheless, just such an aim determined the main direction of the work of this group of researchers, their pupils and colleagues. In spite of the fact that qualitative analysis of the properties of motion was used in "problems similar in mathematical type with those problems which appear in tasks having cosmogonic value," the majority of these complex and exact investigations turned out to be deprived of cosmogonic significance. This is also because members of the group had no personal cosmogonic views and sympathies. Problems for study were selected basically according to their mathematical properties, and the investigated pure schemes often pertain to maximum particular questions which only very conditionally can be called cosmogonic. But even in those cases when the cosmogonic significance of a question is not subject to doubt (for example, in the majority of works of N. F. Reyn), the actual purity of the scheme extremely

narrows the circle of real applications of the strict conclusions which are obtained.

Thus, a series of articles by N. F. Reyn (1933-1936) is dedicated to condensation inside a dust nebula. By analyzing the pure schemes mass, rotation and stability of the condensation are studied. In an introduction Reyn wrote: "The equipment we use is essentially the apparatus of celestial mechanics, whereas the cosmogony of our days relies chiefly on the equipment of theoretical physics. We consider, however that similar mechanical schemes, although not full in themselves, but not contradicting other, temporarily omitted characteristics of the real object being investigated, are of sufficient value for the problem of cosmogony. This is why it seems to us appropriate to conduct preliminary investigation of the question within the framework of a strict mechanical scheme. It stands to reason that in this respect the development of an investigation cannot be considered completed; bringing into consideration factors of a physical character should revive our abstract scheme, nearing it to true reality. Otherwise we would risk reevaluating the role of the mechanical model, distorting thus the essence of the aim of general cosmogonic theories." Unfortunately neither work on dust condensation or other analogical works obtained the promised continuation and development.

Results of work on revision of cosmogonic theories are given in the survey of N. F. Reyn and N. D. Moiseyev "about the contemporary state of the methodical apparatus of dynamic cosmogony" (1941). It is characteristic that not only the title of this survey, but also the material in it is systematized not with respect to objects of cosmogonic investigation, but with respect to pure mechanical schemes which were subjected to investigation. Of the individual critical works one should note the large article of N. F. Reyn, dedicated to the cosmogony of Jeans. Being attracted by detailed analysis and criticism of the separate models and schemes mathematically examined by Jeans, the author bypassed in full silence the question about the inability of the hypothesis of Jeans to explain the large dimensions of the planetary orbits.

this important deficiency of Jeans' hypothesis was qualitatively shown by Russell in 1935, and was subsequently confirmed by N. N. Pariyskiy (1943-1944) by complex and tedious calculations.

In 1938 the word "cosmogony" vanished from the name of the Chair (department) of Celestial Mechanics of MGU-GAISh, and after the death of N. F. Reyn in 1943 investigations having an evident cosmogonic direction ceased completely. The study of dynamic schemes close to those which appear in cosmogonic questions was continued only from an interest toward qualitative methods of the analysis of motions, which are applied only to systems of bodies undergoing a certain evolution.

Now, more than 20 years after the cessation of this work it is clear that from the cosmogonic point of view the results of the work of the Moscow group of celestial mechanics are very modest: they did not influence the fate of the hypotheses they examined and did not lead to selection of a correct path for further investigations. At the same time the schemes subjected to thorough analysis turned out to be so mechanical and so "pure" that they have only a weak connection with real cosmogonic processes.

At the end of the 1940's an analogous approach to cosmogonic investigations was contained in a number of works of K. N. Savchenko (Odessa), but even they received no use and development.

At the end of the 1930's the cosmogonic hypothesis of Jeans was completely wrecked. It was not enough that Russell showed that this hypothesis, just as the hypothesis of Laplace, is not able to explain the distribution of angular momentum between sun and planets, it turned out to be incapable of explaining even the actual formation of the planetary clusters. In 1939 L. Spitler calculated that substance pulled from the sun would be so hot that it would disperse in space, and not form planets. After these deficiencies were shown, all astronomers surprisingly rapidly rejected the hypothesis of Jeans.

The wreck of the Jeans hypothesis led to a crisis in planetary cosmogony, to doubt in the ability of contemporary science to solve this important problem of natural science. Some astronomers were occupied in searches for an explanation of the distribution of angular momentum and paid no attention to the astrophysical side of the question; others preferred the advancement of qualitative hypotheses, considering application of mathematical methods as premature. V. G. Fesenkov was of the second group. In 1939 he began work on his second hypothesis. Although the investigations of A. M. Lyapunov and E. Kartan refuted the possibility of smooth separation of a revolving liquid mass, this idea was used by Fesenkov in his hypothesis of separation of planets from the sun as a result of rotary instability in it. In 1941 Fesenkov, relying on the investigations of G. Bete concerning nuclear reactions inside stars assumed that rotary instability of the sun set in upon the t[illegible]n from one type of reactions to another. Initially the s[illegible]n of a satellite, removing around 1% of the mass of the sun, [illegible] moving of this satellite as a result of tidal friction a distance of 1-2 astronomical units from the sun and then disintegration into several separate bodies, subsequently transformed into planets were all assumed. "We are still not in a state to judge the details of this process," wrote V. G. Fesenkov. In 1945 the assumption of the separation of a massive satellite was replaced by the idea of formation (as before as a result of rotary instability) of a long projection, the basic mass of which lay beyond the Roche limits, i.e., at 5-10 solar radii. As a result of its disintegration into separate parts the planets appeared, turning initially in direct proximity from the sun.

However, even in 1944 N. N. Pariyskiy calculated the possible rate of increase of the radius of planetary orbits under the effect of tidal friction and showed that considering planets to be at contemporary distances from the sun intervals of time immeasurably larger than the lifetime of the solar system are necessary. Thus, the second hypothesis of V. G. Fesenkov along with other difficulties collided with the problem of distribution of angular momentum. The assumption of the possibility of a calm separation of a projection

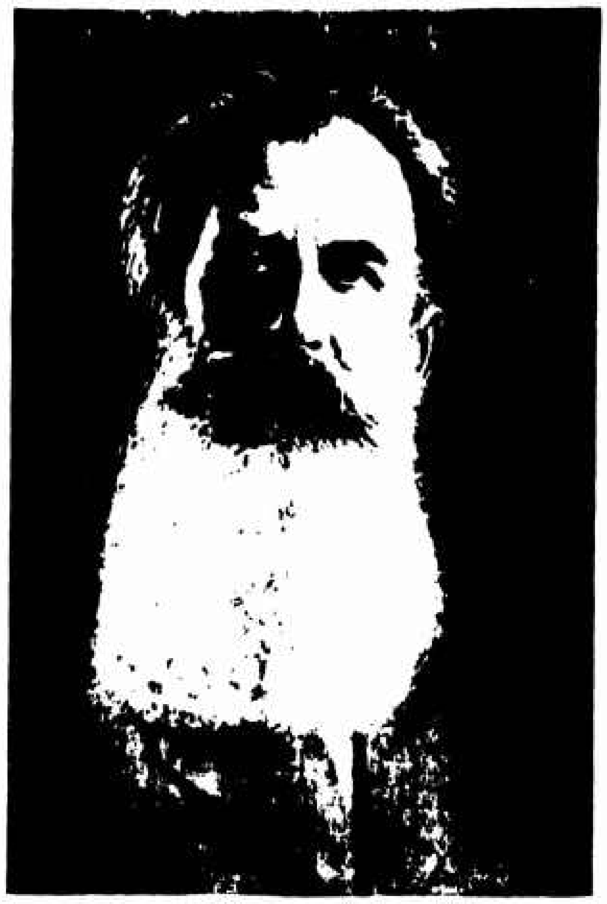
from the sun was incorrect. Despite the erroneous ideas of Darwin and Jeans, it is impossible even for liquid bodies, not even mentioning that stars cannot be likened to liquid bodies. They must be examined as gas bodies, and in such a case their rapid rotation should lead to the outflow of substance from a sharp edge of the lenticular figure.

After 1945 V. G. Fesenkov ceased developing his second hypothesis, and in the 1950's in accordance with the general turn of planetary cosmogony passed to consideration of the formation of planets from a circumsolar nebula.

At the beginning of the 1940's, i.e., just during the years of crisis for planetary cosmogony, O. Schmidt began his work in the field. He arrived at this problem as a geophysicist, needing an historical, evolutionary approach to a study of the structure of the earth. In 1943 Schmidt made his first reports at Kazan, where during the war the Institute of Theoretical Geophysics (which he headed) and also the Institute of Theoretical Astronomy were evacuated. In 1944 the first articles of Schmidt on cosmogony were published, after which followed further articles and numerous lectures and reports. They awakened wide interest toward his investigations and in general, toward cosmogony.

Analysis of the basic regularities of planetary motion led Schmidt to conclude that the opinion of Kant and Laplace about formation of the planets from dispersed substance was absolutely correct. But the only state of matter directly preceding its unification into planets was a swarm of bodies moving along individual elliptic orbits, and not dust or gas nebula.

The sad historical experience of cosmogony showed that independently of any deficiencies inherent to individual hypotheses, for all them the most serious stumbling block was the problem of distribution of angular momentum between sun and planets. Therefore Schmidt turned special attention to this question. He advanced the



Otto Yul'yevich
Schmidt

1891-1956

bold hypothesis that a swarm of bodies appeared near the sun as a result of gravitational capture. In the case of capture angular momentum of the swarm, and consequently also the planets did not depend on the sun – it was taken from the enormous angular momentum of the entire galaxy.

In those years capture, after the expression of Schmidt himself, was excluded from the arsenal of cosmogonic investigations. In the presence of only two bodies capture under the impact of gravitational forces is of course impossible. Celestial mechanics rejected capture in the presence of three bodies, referring to work of Shazi, in which he proved its impossibility, but astrophysicist considered it possible in principle, but not playing a role due to the small probability. Schmidt did not see in the work of Shazi strict proof of the impossibility of capture in the three-body problem. Furthermore, he was convinced that if not with three bodies, then

with four or more it nevertheless is possible. To prove "empirically" the possibility of capture Schmidt turned to the binary stars. In these systems angular momentum is so great that it excludes the possibility of explaining their origin by the separation of once single star. Schmidt introduced in 1944 hypotheses about formation of binary stars by capture and attempted to find statistical characteristics of their orbits, emanating from the hypothesis of capture, but at the same time not depending on the actual mechanism of capture. This attempt was a failure and put Schmidt under the fire of very sharp criticism.

In 1947 Schmidt proved the possibility of capture in the three-body problem, calculating a specific example of similar capture in the approach of three stars.[1] Although only one example was calculated, and only for the case when all motions occur in one plane, from the mathematical properties of the equations of motion it follows that this is not an exceptional case, and, consequently, the probability of capture is finite, and is not equal to zero.

From the cosmogonic point of view the problem of gravitational capture was solved. But from the point of view of celestial mechanics it was interesting to examine the problem in the most general setting – allowing a change of time from $+\infty$ to $-\infty$. G. F. Khil'mi did this using the numerical example calculated by Schmidt.

Proof of the possibility of capture in a three-body problem gave impetus to investigations in this direction. In the Institute of Theoretical Astronomy a series of investigations was conducted dedicated to calculations of different trajectories of capture and criteria of the indissolubility of generators of binary systems (G. A. Merman, V. F. Proskurin, O. A. Sizova, N. G. Kochina, G. Ye. Khrapovitskaya). K. A. Sitnikov gave an analytic proof of the possibility of capture in a three-body problem, not relying on numerical example. Finally, Yu. L. Gazaryan, and then G. A. Merman

[1]Then this example was with greater accuracy calculated by N. N. Pariyskiy, and the accumulation of errors of numerical integration was analyzed by V. F. Proskurin.

published a critical analysis of the work of Shazi which created an incorrect conviction of the impossibility of capture, and confirmed the absence of a strict proof therein.

Besides development of a theory of gravitational capture, a result of the work of Schmidt was attracting the attention of Soviet scientists to other forms of capture — in the participation of the forces of light pressure (V. V. Radziyevskiy), as a result of dissipative processes in the gas-dust medium (L. E. Gurevich).

However the idea of Schmidt that the sun obtained substance for the construction of planets by means of capture also remained as a hypothesis. Neither Schmidt nor his supporters succeeded in finding proofs that in this case capture took place. Furthermore, if the large dimensions of planetary orbits, i.e., in other words, the large angular momenta of the planets, are explained by capture, then it is difficult to explain why the sun slowly revolves around its axis, almost perpendicular to the plane of planetary motions.

Subsequently the attraction to consideration of electromagnetic forces opened a new possibility for solving the problem of moments within the frameworks of the hypothesis about joint origin of the sun and the protoplanetary cloud. Nonetheless the possibility of capture by the sun of the substance for the planets and also of satellites by planets continues to be discussed in cosmogonic literature. Sometimes in favor of capture not mechanical, but chemical arguments are advanced — distinction in relative abundance of two or three chemical elements (in the first place iron) in the earth and meteorites, on one hand, and in the sun on the other.

In the first years of his work in cosmogony of the solar system Schmidt exaggerated the role of the hypothesis of capture in his investigations and considered that results referred to the accumulation of planets from solids essentially depend on this hypothesis. In fact, in considerable measure they are independent from the hypothesis. In fact, in considerable measure they are independent from the hypothesis of capture. This became especially clear after

work of L. E. Gurevich and A. I. Lebedinskiy (1950), in which it is shown that bodies from which the planets were accumulated in turn were formed in the neighborhood of the sun from substance of the circumsolar gas-dust cloud. After the work of Gurevich and Levedinskiy the idea of capture by the sun of a swarm of bodies was replaced by the idea of capture of a gas-dust cloud, which agrees much better with contemporary concepts about composition of interstellar nebulae.

On the first stage of further evolution of the circumsolar cloud from its dust component was formed a multitude of bodies, near in size to asteroids, and then from the swarm of these intermediate bodies the planets were clustered. Due to the opacity of the dust cloud its external zone had to be so cold that in it the condensation of volatile substances was possible. This led to separation of the planets into two groups, distinguished in mass and chemical composition.

The basic regularities of planetary motions — coplanarity and circular character of their orbits — Schmidt explained as the average of individual peculiarities of the movement of separate bodies as they accumulated. Examining the formation of planets not from a dense dust or gaseous environment, as did Kant and Laplace, but from separate bodies, turning around the sun on different elliptical orbits, Schmidt could explain how the huge intervals between orbits of neighboring planets appeared.

Even in 1945 in one of his first cosmogonic works Schmidt gave a mathematical analysis of the rate of accumulation of the mass of the earth. The main feature of the formula of Schmidt, distinguishing it from analogous calculations of other authors, is the calculation of the gradual decrease of the reserve of bodies as they become connected to the growing earth. Examining the contemporary increase of the mass of the earth due to meteoric substance as a continuation of the process of its accumulation, he found that the formation of the earth began several billion years ago (this agrees satisfactorily with other data). Schmidt's formula describes the growth of the

earth due to the substance of its "zone of feeding." But the meteoric substance falling at present on the earth is not, although processed, the remainder of substance of this zone, but appears in the disintegration of asteroids and comets, i.e., arrives from zones more distant from the sun. Therefore, using Schmidt's formula it is impossible to estimate the age of the earth, but it is possible to estimate the duration of accumulation of the majority of its mass. As V. S. Safronov (1954, 1958) showed, the accumulation of 99% of the terrestrial mass occupied a time of the order of 10^8 years.

An important result obtained by Schmidt (1946) is the clarification that the actual mechanism of the growth of planets by the unification of a multitude of bodies includes the principle of adjustment of distances between their orbits. Consideration of the averaging out of angular momenta of united bodies opens the way to explanation of regularity in the distribution of the distances of planets from the sun. The simplest scheme of this process, examined by Schmidt himself, gives a satisfactory presentation of distances for planets of the earth's group and for the giant planets, but leads to a lack of agreement between the theoretical and actual masses of the planets.

Evolution of the swarm of bodies from which the planets accumulated included the change of speeds of their chaotic motion as a result of interaction in encounters, change of the general number of bodies, and also their distribution in mass as a result of unifications and breaking up during collisions. Strict investigation of only the mechanical side of this evolution requires the development of new methods of statistical celestial mechanics. Meanwhile in the evolution of a swarm an essential role belonged to the increase of transmissivity of space and the change of temperature conditions during transition from gas-dust cloud to swarm, which caused a partial evaporation of volatile substances. Only after surmounting these difficulties will it be possible to obtain a law embracing both the growth and mass of the planets.

Schmidt also introduced a great contribution to such an

important question as the appearance of axial rotation of planets. Joint analysis of formulas expressing redistribution of energy and angular momentum in the formation of planets permitted him to show that planets must have straight axial rotation (1950). However, quantitatively the speed of this rotation is defined as the small difference of two large values. It is determined very imprecisely, and therefore V. S. Safranov (1962), trying to develop this question further, could not obtain reliable quantitative results.

From the very beginning of cosmogonic studies Schmidt paid great attention to geophysical conclusions from his new ideas about formation of the earth as a planet. The composition of the earth he considered as close to the average composition of meteorites.[1] The earth was formed in the shape of a cold body, but then in it began the accumulation of heat liberated during the disintegration of radioactive elements, and a gradual heating.

Thus, new ideas about formation of the earth provided a cosmogonic foundation to views on its thermal history and the role of radioactive elements in it, which for many years had been advanced by V. I. Vernadskiy.

In accordance with views of geophysicists conventional then, considering the nucleus of earth to be iron, Schmidt explained its appearance by gravitational differentiation of the depths — gradual dropping down of the more dense iron meteorites and displacing upwards of the lighter rocky substance. It was postulated that this process began after sufficient heating up and increase of plasticity of the earth's substance. However, as the calculations

[1]Up to 1950 when Schmidt proposed that the sun captured a swarm of bodies, he erroneously considered contemporary meteorites as remainders of this swarm, which served as the foundation of the similarity of earth and meteorites. But also after the work of L. E. Gurevich and A. I. Lebedinskiy it became clear that intermediate bodies were not captured, and were formed in the protoplanetary cloud, the foundation of this similarity was preserved, although in essentially modified form: both the earth and parental bodies of meteorites — asteroids — are representatives of an internal zone of the planetary system, heated by the sun and containing bodies of nonvolatile, rocky substances.

of Ye. N. Lyusikh showed (1948), these movements, due to the huge viscosity of substance in the depths of the earth even at present, had to be too slow. A way out of this difficulty (and also from other difficulties resulting from the hypothesis of the iron core) was opened by a hypothesis expressed in general form by V. N. Lodochnikov (1939) and later independently developed by the English physicist Ramsey (1949). According to this hypothesis the earth's nucleus consists of silicate (rocky) substance, similar to the substance of the earth's mantle, but only passing into the dense metallic state by a "jump" under the action of high pressure. Schmidt sympathized with this hypothesis, but did not accept it completely. Subsequently the accumulation of geophysical and cosmogonic arguments in its benefit continued (B. Yu. Levin, 1962).

Articles and reports by Schmidt on his cosmogonic investigations awakened great interest toward these questions. But simultaneously with the wave of widest interest grew also a wave of criticism. Attracting attention to the weak places of the hypothesis, it promoted its advancement. But sometimes this criticism took abnormal character, when instead of discussion of the general direction of research in which there were both achievements and deficiencies, only some deficiencies were examined separately.

The presence of sharply differing opinions on the cosmogonic theory of Schmidt — from acknowledgement of its huge achievement for Soviet science to its complete negation — impelled the Academy of Sciences of the USSR to organize a wide conference dedicated to the discussion of this theory. This First Conference on Cosmogony took place in April, 1951, and gathered more than 300 persons. The basic discussion was the second publication of a book of Schmidt "Four Lectures on the Theory of the Origin of the Earth," containing a presentation of his results, designed for a wide circle of readers. After the report of Schmidt, 40 astronomers, geophysicists, geochemists and geologists appeared before the conference, sometimes sharply critical, sometimes laudatory, and sometimes dedicated basically to an account of their own views. The conference approved Schmidt's work, expressing at the same time a series of serious

critical remarks (first about the hypothesis of capture) and indicating problems of first priority.

In his appearance at the First Conference on Cosmogony, very critical concerning the theory of Schmidt, V. G. Fesenkov, in contrast to his former views, agreed, however, that the planets were formed not from matter separated from the sun, but from the circumsolar cloud. In subsequent years Fesenkov developed an idea (expressed in 1949-1950 by Kuiper) about disintegration of the protoplanetary cloud into massive protoplanets — one for each contemporary planet. Fesenkov considered that the giant planets were formed by compression of the protoplanets without noticeable loss of mass, whereas for planets of the earth's group the protoplanets were 30 times more massive than contemporary planets. Considering that the formation of the protoplanets began on the external region of the cloud and then spread to the sun, Fesenkov connected the law of planetary distances with the gravitational influence of an external protoplanet on the neighboring internal one, which prevented their formation on orbits too closely located. It remained, however, incomprehensible why the weak tidal action of the neighboring protoplanet is dangerous, whereas the 1000 times stronger tidal action of the sun is not dangerous. Besides, it remained vague how the protoplanets of the earth's group lost their excess mass. As I. S. Shklovskiy (1951) showed, the thermal dissipation of gases from clusters of planetary mass is extremely slow and cannot lead to the loss of a huge mass of hydrogen and other volatile elements. Besides Fesenkov considered that the transformation of the proto-earth was fast enough so that the heat being liberated could not disperse in space, but remained in the earth, thereby causing its heated initial state.

In further years, continuing to stress the close connection between the processes of formation of the sun and the planets, Fesenkov leaned toward the idea of accumulation of the planets, and the cold initial state of the earth.

In 1964 Fesenkov wrote: "The sun and the planet were born in

the same process from a certain gas-dust cloud of extremely non-uniform structure, which essentially was an accumulation of numerous condensations in structure resembling contemporary comets. As a result of collisions these condensations started, finally, after formation of a central condensation — the sun — to move chiefly in a forward direction and besides near a basic plane little differing from the contemporary ecliptic plane."

During the 1950's a series of articles about the origin of solar system was published by V. A. Krat. The views expressed in them with respect to certain questions are similar to the theory of Schmidt, especially in that the form which it took on after the work of L. E. Gurevich and A. I. Lebedinskiy (1950). In general, in these years the concept of accumulation of the planets from cold matter and the cold initial state of the earth dominated in planetary cosmogony throughout the world. Thus, now both in the Soviet Union and in the whole world there exists a single view on the basic features of the process of formation of the planets.

Clearly realizing the huge value of the problem of origin of the earth and excellently understanding the complexity of this problem involving a number of sciences and requiring the participation of scientists in the various specialities, Schmidt called upon astronomers, physicists, mathematicians and representatives of the earth sciences to join actively in its development. In 1945 he started to create in the Institute of Theoretical Geophysics a Department of Evolution of the Earth, which would also study the origin of the earth. This department continues its work to this day in the Institute of Earth Physics imeni O. Yu. Schmidt. It is the only scientific collective not only in the Soviet Union, but also in the whole world systematically studying this problem.

Colleagues of the Department of Evolution of the Earth — S. V. Kozlovskaya, B. Yu. Levin, Ye. A. Lyubimova, S. V. Mayevaya, Ye. L. Ruskol, V. S. Safronov and others — have conducted research on many sides of the evolution of the protoplanetary cloud and the swarm of intermediate (asteroid) bodies formed from it, the

accumulation of the planets, their thermal history, etc. In particular, they have studied a series of variants of planetary growth, in which it is considered, first, that in the zone of every planet there is simultaneous growth of several bodies, from which one finally combines with the others and becomes a planet, and, secondly, that during the collisions of bodies along with the unifications there are also splittings. Both that and the other affects the growth rate of a planet and the initial distribution of temperature. Analysis of the change in time of the distribution function of the intermediate bodies with respect to mass showed that a considerable part of the mass of the earth (and the other planets) came from large bodies up to 10^2-10^3 km in size. This resulted in temperature heterogeneities in the depths of the earth, which had to be reflected in the further evolution of the planet. Just such primary heterogeneities could be the cause of the nonuniform melting of the earth's crust from the upper mantle, which is seen now in the existence of continents and oceans.

The decrease in masses of the giant planets with distance from the sun was explained by the fact that these planets, attaining sufficiently great masses because of their natural perturbations ejected still "uncaptured" matter from their"feeding zones," thereby ceasing further growth. The further from the sun, the less the mass of a planet necessary for such ejection. Solids in the zone of giant planets had the same ice composition as the nuclei of comets. Therefore their ejection beyond the limits of the planetary system was at the same time the formation of the gigantic cloud of comets which surrounds the solar system and from which arrive the comets which are now observed.

A quantitative development was begun on Schmidt's idea about the formation of a swarm of bodies around the growing planets, serving as material for the satellites. It was shown that the mass of the circumterrestrial swarm had to be sufficient for the formation of the moon. The moon had to be formed on the concluding stage of the accumulation of the earth at a distance of 10-20 terrestrial radii and then moved from the earth due to tidal friction.

Calculations of the thermal history of the moon showed that 1-2 billion years after formation its interior melted. During this time the moon, moving from the earth, captured the external parts of the circumterrestrial swarm and the impacts of the large bodies led to formation of the lunar seas and the lava-flooded circuses.

The joint formation of the earth and the moon had to lead to their identical composition. This will agree with the Lodochnikov-Ramsey hypothesis about the earth nucleus from metallized silicates, but will not agree with the old concepts about an iron nucleus. But even with identical composition of earth and moon, in the thermal history of their interiors there must be very great differences. Pressure in the moon's interior is small and weakly affects the melting point of the matter in the depths. Therefore the depths of the moon, in contrast to the earth's depths melted up to the center and were subjected to physicochemical and gravitational differentation, accompanied by movement to the surface of a considerable portion of radioactive elements. This led to the transition from heating of the moon to cooling, and now the external layer of 500-800 km including 60-80% of its matter, should be hard, whereas the central parts remain semiliquid.

The above examples show that it is possible to advance in a wide range of questions of planetary cosmogony, relying on the cosmogonic theory of Schmidt — theory which considers the evolution of a gas-dust protoplanetary cloud and formation of the planets from it and which includes results obtained by both Schmidt and his supporters, colleagues and followers.

Soviet planetary cosmogony has come a long way — from the consideration of separate particular questions, as was done in prerevolutionary Russia, through the stage of critical analysis of existing hypotheses and theories to an honorary place in the front line of world science. This success in considerable measure was due to a conscious materialistic approach to research — the tendency to set a true process of development, not limited to

hypothetical explanation of an individual group of facts, and to the tendency toward collective investigations, embracing various sides of the evolutionary process.

LATEST PROBLEMS IN PLANETARY COSMOGONY

At the present time thanks to the accumulation of a large amount of observational material and various theoretical results obtained in considerable measure thanks to the application of new methods, it was made clear that the origin of the planets is intimately connected with the evolution of our galaxy, the origin of the stars, and also with the study of the substance of meteorites with all its characteristic peculiarities.

A deficiency of former hypotheses in planetary cosmogony was in particular that they either conpletely or almost completely neglected processes of stellar-cosmogonic character, which, as now is clarified, in many respects determine not only the formation, but also the chemical composition and internal structure of the planetary bodies.

A series of basic positions which should lie at the foundation of planetary cosmogony can be considered as set, but the actual genesis of the planets is very complex and still by far cannot be considered as completely clarified.

Already the fact that the sun and the planets differ in the identical relative abundance of different heavy elements shows that they had to be formed in one epoch of existence of our galaxy, which, as it is known, is continuously enriched with heavy elements.

Further, it is established that the age of the radioactive elements themselves comparatively differs only somewhat from the age of the earth. This is an independent argument, indicating that the sun and planets appeared simultaneously and, consequently, the formation of the planetary systems is impossible to separate from the formation of the stars.

The study of young, recently appearing stars and the surrounding gas-dust nebulae presents special interest for planetary cosmogony. In connection with this calculations of E. A. Dibay and S. A. Kaplan are very interesting (1964), showing on the basis of gas dynamics that globules in diffuse nebulae must be rapidly compressed by the surrounding hot gas, as was earlier (1953) noted by A. I. Lebedinskiy. Calculations of Ye. L. Ruskol (1955) showed that similar compression was sufficiently fast under the action of gravitational forces, even in the case of an isolated globule. Development of these ideas lay at the basis of Cameron's (United States) theory of the rapid transition of a similar globule to the star stage with liberation of nuclear energy, while ionization of the surrounding neutral gas and formation of considerable magnetic fields goes on.

The large role of similar fields in the early history of the solar system was examined in detail by Alfén. At the same time, the shock waves appearing during the formation of stars, which begin to ionize the surrounding medium rapidly, and even more so during supernovae flares, strongly promote compression of the neutral gas and condensations of gas-dust nebulae.

In connection with this we should especially note the work of V. A. Ambartsumyan, and also E. A. Dibay on the connection of comet-shaped nebulae with recently formed stars of the T-Taurus type and detection of nonstationary objects in the same type at the Herbig-Haro objects, confirming the speed of separation of stars from prestellar condensation.

Detailed investigation of gas-dust nebulae surrounding young, recently formed stars, shows that they differ by a multitude of

heterogeneities occupying only an insignificant part of the whole volume of the nebula. For example, according to A. Osterbrock and A. Flaver (United States), for the Orion nebula it was found that these heterogeneities, representing almost the entire mass of the nebula, occupy only 0.03 of its volume. Analogously to this we might study the extended cometary cloud, extending from the sun to one hundred -- one hundred fifty thousand radii of the earth's orbit (G. A. Chebotarev) and according to Oort consisting even none of approximately 100 billion separate comets. Earlier the number of them in this cloud had to be much greater. It is fully possible that even the primary gas-dust cloud, surrounding at first the general gravitational center around which orbital motions were accomplished, consisted of independently moving similar heterogeneities, among which there were inevitable numerous collisions.

Thus, the first problem of planetary cosmogony is the processes accompanying rapid separation of the sun from the medium of a gas-dust nebula in which separate condensations, possibly of the cometary type, had to remain in large quantity. In general, the dynamic peculiarities of a planetary system as a rule can be explained sufficiently well if one were to originate from the position that the substance of the planets was not liberated in the past from the sun itself, and was only connected with it by being included in the same protoplanetary cloud, whatever its origin and structure. Evolution of the protoplanetary cloud occupied A. I. Lebedinskiy and L. E. Gurevich and especially V. S. Safronov, who obtained a series of interesting results explaining the different peculiarities of planetary motions.

The second problem of planetary cosmogony is clarification of the process of formation of the most ancient substance in the planets, which at present is assumed to be of carbonaceous chondrites. It is an absolutely astonishing combination of crystal chondrite, which could be formed at a comparatively high temperature with rapid cooling, and rather complex organic compounds, as is now admitted, of an abiogenetic nature (G. P. Vdovykin and others). Thus, for example, in meteorites of this kind (Orgueil, Cold Bokkeveld, Marrey [Translator's Note: exact spelling not found]), besides the usual H_2, He,

H_2O, CO, Ar^{40} gases there are such complex compounds as C_6H_5 $[CH(CH_3)_2]$; $C_6H_4(C_2H_3)_2$ anthracene, phenanthrene, and also the inert gases Kr, Xe with various isotopes, SO_2, CS_2, NO and others. The dark variety of certain meteorites is especially rich in inert gases in contrast to the light variety of the same meteorite (for example, in the rantar meteorite).

As is know , primary hydrocarbon compounds will be formed even in interstellar space and are in cometary nuclei in abundance. There are two hypothese about the origin of similar compounds. The first is that it is an unbalanced high-energy process, for example, electric discharges, irradiation by ultraviolet radiation (experiments of F. D. Miller (United States) and A. G. Pasynskiy). Whipple also assumes similar electric discharges (United States) in the proto-planetary nebula, but this apparently requires continuity of the gas component in its medium, which is incompatible with the presence of separate isolated condensations.

The other hypothesis proposes equilibrium reactions in the fractionated gas phase. Experiments, and also calculations of H. Suess (United States) show that considering an abundance of hydrogen with respect to carbon decreased in comparison with the cosmic abundance, at high temperatures (for example, near 600-800°C) and a pressure of several atmospheres, especially in the presence of the impurity of meteoritic dust as catalyst, equilibrium is reached rapidly and methane (CH_4) is formed, and then more complex compounds, rich aromatics (Fischer-Tröpsch reactions). These reactions can reproduce even the rare parts of distribution in meteorites of organic compounds. Hence the conclusion is made that during the formation of the solar system separate local regions were heated to a temperature of the order of 1000°C. The gas mixture somewhat was packed and then rapidly cooled over seconds or months — such are the limits of cooling time. Similar processes apparently mostly correspond to collisions among themselves of individual heterogeneities of cometary type, already rich in primary hydrocarbons, different gases, and also heavier elements.

In general, carbonaceous chondrites give interesting information with respect to processes occurring in the early stage of existence of the solar system.

A special problem is the presence in meteorites of disintegration products of different short-lived elements, for example, xenon-129.

As was shown by an investigation of isotopes of the Aroos meteorite, made immediately after its fall in the autumn of 1959, similar comparatively heavy elements will not be formed during ordinary irradiation by cosmic rays or under the influence of the solar wind. In this meteorite around 30 isotopes show up, but only up to atomic weight 40, appearing during irradiation in outer space over millions of years. To produce the heavier isotopes in the carbonaceous chondrites, much more powerful radiation is required. Reynolds (United States) considers that they are formed during galactic nucleosynthesis, but Fowler (United States) and Cameron assume that this can be the result of irradiation of planetisimals by neutrons and fast protons. Not going into detail, we will show, however, that R. Pepin (United States) found the presence of a compound of xenon-129 with plutonium-244, and the last element (half-life 76 million years) is able, due to its huge atomic weight, to be formed only during the very highest-energy reactions and, consequently, only in the process of galactic nucleosynthesis.

Then R. Fleischer, R. Price and R. Walker (United States) according to the tracks of an isotope of plutonium-244 calculated the time interval between termination of nucleosynthesis of the matter of the solar system and solidification of meteoritic substance. This interval was the same as for iodine-129, which with a half-life of 12.5 million years passes into xenon-129. All of this, as it were, indicates that shortly before the formation of the solar system, there happened in the neighborhood galactic nucleosynthesis, the burst of a Supernova, enriching with heavy elements the neighboring regions occupied by gas-dust nebulae, and as a result of the shock waves accompanying them of comparatively fast condensation.

This again shows that the formation of the solar system - the sun and planets - was intimately connected with the general processes occurring in our galaxy.

Further, during the development of parts of the possible process of formation of the solar system it is necessary to turn attention also to the appearance and character of motion of regular and irregular satellites and especially to the distinction of the physical nature of the plantes, which apparently is intimately connected with their angular momentum. Here again appears an extreme heterogeneity of structure of the primary protoplanetary nebula, as a result of which could be formed, on one hand, such unique bodies as a double planet earth-moon with large angular momentum and with an intense magnetic field, connected with a sharp differentation of matter, and on the other - the neighboring planet Venus with slow counterrotation, deprived satellites, without noticeable magnetic field, but with a very high surface temperature, excluding any possibility of life.

Explanation of similar heterogeneities in the solar system also presents one of the basic problems of planetary cosmogony and is especially necessary for correct understanding of the character of the drawn-out evolution of the planets. In particular, the degree of differentation of the substance of a planet depends in large measure on the nature of the sources of the initial heating up.

Above it was indicated that formation of a series of short-lived isotopes practically coincided with the time of formation of the solar system itself. The structure of iron-nickel meteorites, which undoubtedly are formed when the bigger asteroid bodies split, visually shows that similar bodies, being very small as compared to planets, nevertheless were subjected to rather enough considerable initial heating, reaching approximately a thousand degrees. As far as it is possible to judge, similar heating up can be ascribed only to disintegration of short-lived elements.

In general, the sources of heating which determine the thermal evolution of a planet can be different. The correct presentation about their relative role is very important for calculating the

thermal history of the earth and the planets, determining their present physical properties, secondary atmospheres, liberation of water vapors and at the same time the origin, and consequently also the possibility of the existence of life.

All of this shows that contemporary planetary cosmogony embraces an extensive circle of different problems, which can be solved only with the combined efforts of specialists of the different scientific disciplines.

COSMOLOGY

Contemporary cosmology constitutes a division of astronomy intimately connected with theoretical physics and touching the radical problems of philosophy.

According to the most wide-spread determinations, cosmology is the science of the universe as a whole, teaching about the universe as a whole or even the theory of the universe as a whole. Sometimes in these determinations instead of the universe we speak of the world, but the expression "as a whole" is replaced by the expression "on the whole." These determinations are not free from objections. After all, a direct check by observations in principle can be used only for those conclusions of cosmologic theories which pertain to an actually observed part of the universe. It is obvious also that only from a study of this part of the universe does cosmology acquire the information lying at the basis of its theories. Therefore sometimes cosmology is defined as the theory of everything known, i.e., that part of the universe included in observations. But similar determinations also encounter objection. The fact that no part of the universe is impossible to consider as an isolated system and its theory is inconceivable without a theoretical exit beyond its limits. This is on one hand. On the other hand, if a verification of cosmologic theory by observations requires directly empirical, mainly astronomical data, i.e., information with comparatively small cosmologic projectability, then the bases of cosmology require furthermore, laws of physics, in other words, basic physical theories possessing

incomparably greater ability to be extrapolated, and also philosophical principles, which in general have meaning only to the extent that their absolute cosmologic ability to be extrapolated is not subject to doubt, although they, just as any other information, are derived from the study of only a part of the universe known to us.

What was said here about philosophical principles becomes evident if we rememb r the most important — the principle of materialistic monism. Hence, it is clear that the limitedness of the region of the universe known to us in itself does not exclude an arbitratily great projectability obtained from its study of information: the project-ability of information is even greater the greater the community. Regarding, however, conclusions of cosmology which lead us beyond the limits of the known part of the universe and composing the teaching about the universe as a whole, then the criterion of the truth of these conclusions can be whether or not they hold when the basic physical theories at the basis of cosmology, are replaced by new, more general theories, consequently relying on an incomparably more extensive circle of facts. Such is the unique criterion of practice in cosmology.

Considering everything said, we arrive at the following definition: cosmology is the physical teaching about the universe as a whole, including the theory of everything enveloped by astronomical observations of the world as a part of the universe.

Paradoxically, negation of the admissability of teaching about the universe as a whole, founded whatever considerations about the universe is logically contradictorily, inasmuch as these actual considerations can be examined as elements of such teaching, but the negation of its admissability excludes the admissability of the above considerations.

It is clear that it is possible to combine an occupation with cosmology and even cosmologic investigations with an indifferent relationship to its definition. But in this case the confidence of a person that he is studying exactly cosmology and not any other science, and that he has a right to consider himself a cosmologist

may be justified by only the following definition, which is a paraphrase of a certain definition of geometry: cosmology is a science which is studied by people calling themselves cosmologists.

Contemporary cosmology examines the distribution, interaction and motion of the masses in the universe, their physical state and its change in time, the geometric properties of outer space. The evolution of the observed part of the universe connects cosmology with cosmogony.

As we already mentioned, the basis of cosmology is information of three kinds. First, empirical, mainly astronomical data. Secondly, laws of physics, in other words, basic physical theories. Thirdly, philosophical principles.

Information of the first kind can be examined as information about the steps of stairs, i.e., a sequence of objects of various scales and various degree of complexity. By joining certain adjacent steps into one, it is possible to bring the total number of steps to six. It is the same thing if we go from greater scales to smaller: the world of galaxies and their ensembles (supergalaxies, clusters and groups of galaxies, multiple systems); the world of stars and stellar ensembles (clusters and associations, multiple systems); the world of planets, satellites and their systems (planetary and satellite systems); the world of macroscopic bodies (they should include the meteoric bodies); the world of molecules and atoms; the world of elementary particles. The first three steps constitute the realm of gravitation (in which, however, an important role is played by magnetic fields) and the region of astronomical observations, and the three following – the realm of nongravitational interactions and the region of physical experiment.

These steps are enumerated in the following diagram.

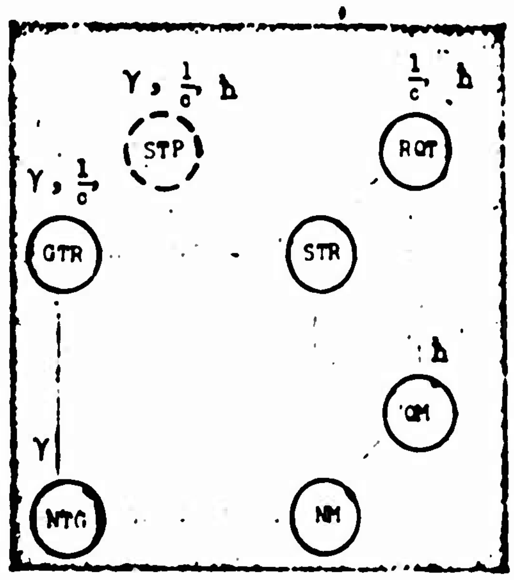
World of galaxies and their ensembles World of stars and stellar ensembles World of planets, satellites and their systems	Realm of gravitation	Region of astronomical observations
World of macroscopic bodies World of molecules and atoms World of elementary particels	Realm of non-gravitational interactions	Region of physical experiment

Information of the second kind constitutes the totality of basic physical theories, i.e., theories containing the basic laws and concepts of theoretical physics. This includes first of all: Newtonian mechanics (NM); Newtonian theory of gravitation (NTG), an expansion of the basic NM concepts to the region of gravitational phenomena; special theory of relativity (STR), the result of reconstruction of the basic NM concepts, necessary, first of all, in the region of high speeds; nonrelativistic quantum mechanics (QM), the result of reconstruction of the basic NM concepts necessary in the region of phenomena of the microcosm; general theory of relativity (GTR), in other words, Einstein's theory of gravitation, constituting a generalization of the STR to the region of gravitational phenomena and at the same time a generalization of the NTG to the region of high speeds and strong fields of gravitation; relativistic quantum theory (RQT), a generalization of the STR concepts to the region of the microcosm and at the same time a generalization of QM to the region of high speeds and high kinetic energies.

Among existing basic physical theories there is no theory which would be the most general of all. It would have to be either a synthesis of the GTR and RQT, or the substitution of such a synthesis showing its fundamental impossibility. Such as yet unconstructed

theory we conditionally call a single theory of physics (STP).

The relationship of the seven theories can be represented by the following diagram, on which the arrows are directed from less general theories to more general theories. The diagram shows three universal constants which are in fundamental equations and other formulas of corresponding theories: gravitational constant γ (NTG, GTR, STP), reciprocal of fundamental speed 1/c (STR, GTR, RQT, STP) and Plank's constant $\hbar$ (QM, RQT, STP).



Information of the third kind is philosophical principles and positions, ontologic, gnoseologic and logical. They always - clearly or implicitly, but inevitably - play an important and occasionally a directing role in cosmology.

On one hand, of the basic physical theories for astronomy in general, for cosmology in particular a special role is played by the theory of gravitation. On the other hand, the main field of application of the latter is astronomy, and the distinction between the Newtonian and Einstein theories of gravitation and the connected concepts of the properties of space and time has the strongest effect in cosmology.

The epoch when astronomy studied the world of stars up to the discovery of the world of galaxies was together with that the epoch of supremacy of Newtonian physics, including the particular ideas

about space and time and the Newtonian theory of gravitation. This was the epoch of prerelativistic cosmology. Characteristic are the appearance of thermodynamic, photometric and gravitational difficulties of cosmology, known as the theory of thermal death of the universe, photometric paradox and gravitational paradox, and different hypotheses having as a purpose the removal of these difficulties. But in this epoch ideas were engendered and developed, which later were the basis of a new theory of gravitation – the ideas of Gauss, Lobachevsky, Boyyai [Translator's Note: Russian word Бойя, may be Бойля – Boyle], and Riemann. And at the end of this epoch a special theory of relativity was created and are the first ideas of quantum mechanics formulated.

The discovery of the world of galaxies and the metagalactic red shift coincided in time with the appearance of a general theory of relativity, i.e., Einstein's theory of gravitation. This was the beginning of the epoch of relativistic cosmology. The formal beginning of this epoch should be considered as 1917, the year in which the new theory of gravitation was used by its author in cosmology. Thus, the semicentennial of Soviet cosmology is the epoch of development of relativistic cosmology.

As is known, the first relativistic models of the universe were static. Discovery by the Soviet scientist A. A. Fridman (1888-1925) of the first nonstatic relativistic models of the universe signified the beginning of the first phase in development of the theory of a nonstationary universe. Discovery of the red shift stimulated development of this theory. Development of nonrelativistic cosmology simultaneously continued. It was stimulated on one hand by the discovery of the world of galaxies, and on the other by the difficulties which met the uniform isotropic relativistic cosmologic models, founded on the general theory of relativity, during comparison with data of extragalactic astronomy and cosmogony. But these difficulties, partly real, partly imaginary, led to other consequences. On one hand, they led to discussion of development of the theory of an anisotropic nonuniform universe on the basis of a general theory of relativity and, later, to the first steps on the road to a solution

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of this problem. The problems of construction, first, of a theory of the universe, anisotropic and nonuniform (on a large and even on an arbitrarily large scale) were examined; secondly - theory of the universe, anisotropic (for example, revolving), but uniform; thirdly, - theory of the universe, isotropic and uniform on a large scale, but locally nonuniform. On the other hand, the above difficulties led to attempts to modify the Einstein theory of gravitation and even complete rejection of it as a theoretical basis of cosmology. A certain role in stimulation of these directions was played by the actual discovery of the nonstatic models of the universe, inasmuch as it demonstrated the fact that Einstein's theory of gravitation gives a multitude of models for the universe existing as the "only sample" - a fact causing doubt of the absolute cosmologic projectability of this theory. Within the bounds of these directions certain ideas were expressed and used which can turn out to be the anticipation of a new phase in the development of physics and cosmology. The possibility of such a phase, besides because of the mentioned doubts of the

absolute cosmologic projectability of Einstein's theory of gravitation, is indicated also by the creation of quantum theories, nonrelativistic, and then relativitistic, also occurring in the epoch of development of relativistic cosmology: their appearance showed the probability of construction of a new physical theory, more general than Einstein's theory of gravitation.

Development of a relativistic theory of gravitation and increase of interest toward it was stimulated not only by cosmology and the quantum theory of a gravitational field, but also by gravity waves, the problem of energy and pulse of a field of gravitation, and also the problem of structure and development of supermassive bodies — quasars. Their discovery led to the birth of a new division of science — relativistic atrophysics.

In the most recent years the discovery of isotropic equilibrium cosmic radio emission gave a new push to development of cosmology, first of all to the study of physical processes in the universe.

All the above directions were represented in the research of Soviet authors. These investigations are characterized by: pioneer works in the theory of a nonstationary universe in relativistic cosmology; preference toward nonrelativistic theories, and then to relativistic theories of an anisotropic nonuniform universe as compared to attempts to overhaul and alter Einstein's theory of gravitation; pioneer works in development of concepts which can lead to synthesis of a general theory of relativity and a relativistic quantum theory, in other words to the creation of a new theory of gravitation, coinciding with the single physical theory or the essential part which makes it up; active particpation in development of relativistic astrophysics and study of physical processes in the universe. At the same time for many investigations attention to the philosophical side of cosmologic theories and to questions about subject, method and understanding of cosmology are characteristic.

1. There exist two formulations of the photometric paradox. According to one of them, not considering a finite extent of light

sources, the visible surface brightness of the sky under certain natural assumptions shown below, should be infinite. According to the other formulation, considering a finite extent of stars and consequently, their mutual shielding, the visible surface brightness of the sky under the same assumptions should be equal to a certain average surface brightness of the stars. In other words, the cosmic field of radiation should have the same density as equilibrium radiation, the temperature of which is equal to a certain average effective temperature of radiating objects, i.e., the stars. Thus, the dilution factor should be equal to unity, whereas it is 14 orders less. Distinction in formulations of the photometric paradox does not render an essential influence on conditions of its removal.

Assumptions leading to the paradox can be formulated in the following way. First, the average of the number of radiating stars arriving per unit volume over all outer space is not zero. Secondly, this quantity even in the past has not always been equal to zero. Thirdly, stellar radiation does not undergo a decrease in energy on the way from source to observer. Fourth, there are no other factors lowering the visible surface brightness of stars. Fifty years ago two methods of removing the paradox were known. One of them, already prevailing 70 years, consisted in rejection of the third of the enumerated assumptions, namely the reference (V. Struve) to absorption of light by dark cosmic matter. The other, known then for a decade, consisted in rejection of the first two of four assumptions, namely acceptance of the theory of hierachic structure of the universe (Charlier).

The first Soviet cosmologic work, appearing in 1918, belongs to V. G. Fesenkov. It was the first in cosmology to consider that dark cosmic matter not so much absorbs as disperses light falling on it. Therefore dark cosmic matter should not lower the brightness of the night sky, but considerably increase it. This signified an absolutely new approach concerning the role of dark matter in the universe. In the work it is shown that calculation of scattering of only sunlight already gives the upper limit for the average density of dark matter in the universe. It is obvious first that these results, undermining

the ruling method of removing the photometric paradox by reference to the absorption of light, increased the value of the theory of a hierachic structure, removing the paradox without such a reference. Secondly, these results showed how it is possible to judge the structure of the universe by the luminosity of the night sky. Thirdly, they portended the necessity of further development of the theory of a heirachic structure taking into account the presence of dispersing matter, inasmuch as it does not promote, but hinders removal of the photometric paradox. In connection with all these results of V. G. Fesenkov they were developed by him two decades later. In contrast to the work of 1918, scattering of not only the first but of all orders was considered.

2. The initial program of the general theory of relativity, reflected in its name, required that the forces of inertia be explained by the joint action of all masses of the universe. Formulation of such an understanding of the nature of forces of inertia is sometimes called the material postulate of the relativity of inertia. Only if this principle were valid inertia would exist only with respect to masses, but not relative to empty space, and the physical distinction between various systems moving relative to each other with acceleration (in particular, rotationally and irrotationaly), would result from the distinction in their motion with respect to masses and would not contradict the idea of their complete physical equivalence, more precisely, the sameness of all systems of reference with respect to each other. However, the presence of defined space-time metrics is sufficient for the existence of forces of inertia. Therefore the theory of gravitation satisfies the material postulate of relativity of inertia only when it does not allow the possibility of some defined metrics in the complete absence of any and all masses, including mass connected with gravity waves. Since the equations of Einstein without cosmologic constant allow such a possibility, they do not satisfy the mentioned postulate. Together with this these equations do not allow a static model of the universe filled with masses and possessing the properties of homgeneity and isotropy. That the Metagalaxy was dynamic still was not known: the radial velocities of only several galaxies were measured, showing a

predominance of positive speeds over negative (i.e., red shifts over violet) at large values of speeds.

Einstein went to the simplest generalization of his own equations by supplementing them with an additive cosmologic term which was proportional to a new, cosmologic constant. Later it was clarified that such a generalization is the only one which does not increase the order of equations of gravitation and does not contradict the law of conservation of energy and momentum. In the Newtonian approach the presence of a cosmologic constant in equations corresponds to the existence of hypothetical additional forces, proportional to distance: for a positive cosmologic constant this means repulsive force, and for negative it is an attractive force. Einstein found a uniform isotropic static model with a closed space of positive curvature filled with dust (i.e., not producing pressure) matter, — a model satisfied by generalized equations with a positive cosmologic constant. The space volume of this model and the included mass depend on the value of the cosmologic constant, such that the volume is proportional to the cube of mass. Consequently, without masses this model is inconceivable. This circumstance was interpreted as evidence that the equations of gravitation with a positive cosmologic constant satisfy the material postulate of the relativity of inertia.

To counterbalance these conclusions the Dutch astronomer W. de Sitter proposed another cosmologic model, also satisfying equations of gravitation with positive cosmologic constant. This model, similarly to the model of Einstein, is static and possesses a finite space of positive curvature, but the average density of matter in it is equal to zero: the model is empty. This meant that the Einstein equations do not satisfy the material postulate of relativity of inertia (that this postulate is not satisfied by equations with negative cosmologic constant was obvious). In the model of de Sitter acts a field of repulsive forces (in the Einstein model they are balanced by the attraction of the masses), leading first to a red shift in the spectra of remote light sources, and secondly to inevitability of their motion, which causes both red and violet shifts. This permitted interpreting within the bounds of the de Sitter

model the observational data of that time. Later, when it was clarified that violet shifts are an exception peculiar to only three galaxies of those nearest, Weyl introduced a special hypothesis of ordering of the speeds of galaxies, in order to coordinate them with the de Sitter model. Clearly, galaxies in the de Sitter model can be examined only as a kind of test bodies, whose mass (even in totality) is too small to influence the properties of space and time.

Interpretation of the de Sitter model as empty was disputed by Einstein and Weyl. The fact is that in the model a certain distance from every point the repulsive forces from this point become infinite, and the rate of time flow drops to zero: at this distance passes the "horizon," consisting of special (singular) points. Einstein interpreted the presence of these peculiarities as a manifestation of the presence of mass in the model, distributed with infinite density, and Weyl even calculated, under certain assumptions, the magnitude of this mass. In the argument between supporters of the two points of view, different arguments were expressed, not leading, however, to any solution.

Besides the two models – Einstein (E) and de Sitter (S) – also a third was examined – de Sitter-Einstein model (SE), which is obtained from both the first and the second as a result of passage to the limit to the case of a cosmologic constant equal to zero. This model makes up a world of special theory of relativity with a static infinite Euclidean space and average density of mass equal to zero, where, however, the total mass can be both equal to zero and infinite. Still earlier Einstein and Grommer established that the equations of gravitation without a cosmologic constant allow a cosmologic model in a state of statistical equilibrium. But in it the density of matter at infinity, and also the average density of matter over all infinite space is equal to zero, although the total mass is infinite. Furthermore, in it peculiar speeds of objects in outer space, arbitrarily close to the velocity of light must be observed, which contradicts observational data.

As a result, by the time the first work of A. A. Fridman appeared the following situation had formed in relativistic cosmology.

It was clear that equations of gravitation without a cosmologic constant or with a negative cosmologic constant do not satisfy the material postulate of relativity of inertia. The question of whether equations with positive cosmologic constant satisfy this postulate remained controversial, inasmuch as it was vague whether the de Sitter model could be examined as empty. For equations without a cosmologic constant only a possibility of infinite space and infinite mass was known, but with an average density equal to zero. For a positive cosmologic constant only the possibility of finite space and singular model in which matter is distributed evenly with average density not equal to zero were known. In connection with the opinion according to which equations with positive cosmologic constant satisfy the material postulate of relativity of inertia, this created the impression that the general theory of relativity can provide a simple cosmologic model and requires acknowledgement of the finiteness of space.

3. In his first cosmologic work (1922) A. A. Fridman kept all assumptions of Einstein, except the assumption of staticness. He investigated nonstationary uniform isotropic models with a (closed) space of positive curvature filled with dust matter. The nonstationarity of the examined models is described by the dependence of radius of curvature and density on time, where density changes in inverse proportion to the cube of the radius of curvature. Fridman clarified the types of behavior of such models, allowed by equations of gravitation, where the model of Einstein turned out to be a special case, and introduced classification of these types, which has been kept until today with small changes (see the figure on p. 435, case $k = +1$, types E, A_1, A_2, M_1, M_2, O_1). Fridman's work examined exact nonstationary solutions of gravitation equations for the first time. The work demonstrated that these equations allow cosmologic models in which matter is distributed continuously with average density not equal to zero (positive), not only with a positive, but also a negative and equal to zero cosmologic constant. The work of Fridman at first encountered erroneous objections from Einstein, but then after clarification of Yu. A. Krutkov he recognized it, and later on the basis of the work of Fridman he found the cosmologic constant to

be unnecessary (at present the majority of authors considers this constant equal to zero).

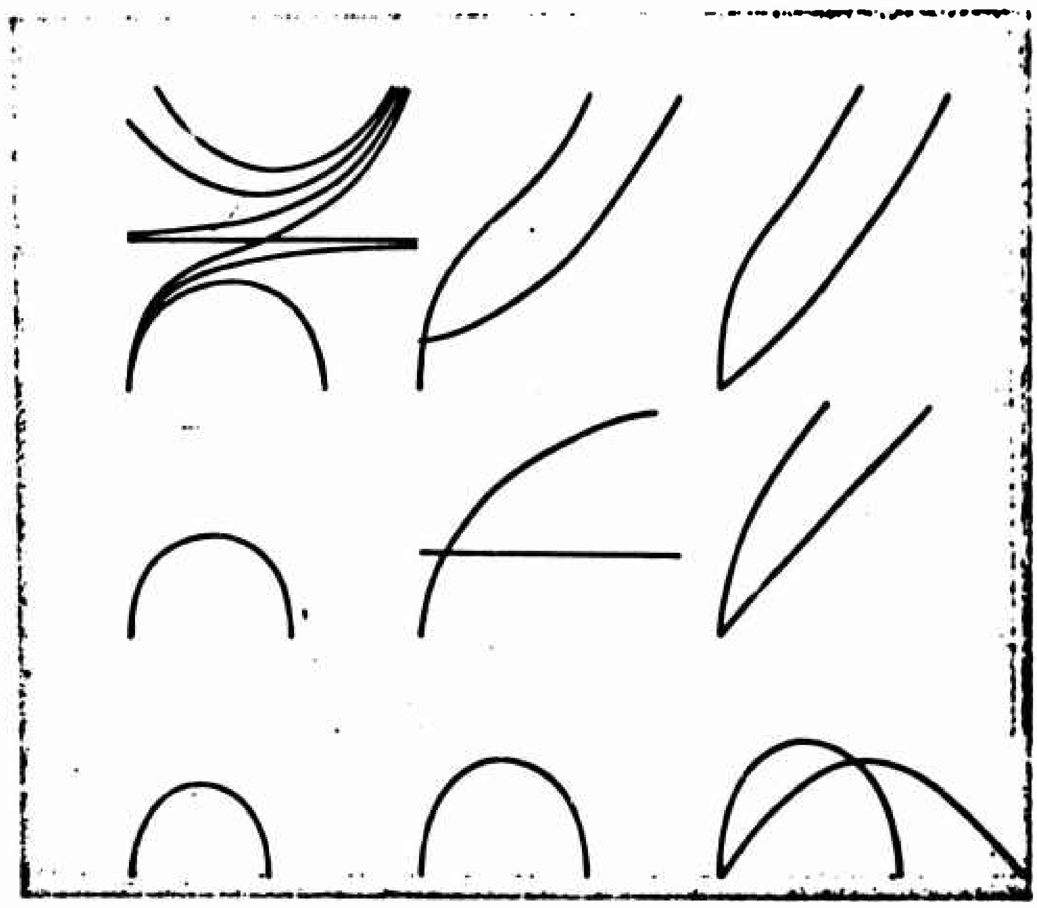
The second cosmologic work of Fridman, published in 1924, was dedicated to a refutation of the opinion according to which the general theory of relativity requires acknowledgement of the finiteness of space. He recalled that the curvature of space with respect to itself without certain additional assumptions about the properties of the connectedness of space, is not sufficient for conclusions on the finiteness or the infinity of space, and that if the usual additional assumptions require finiteness (closure) the everywhere isotropic space of positive curvature, then they require infinity of the everywhere isotropic space of negative curvature. (However, it must be noted that in application to cosmologic models these additional assumptions are inevitable from physical considerations. Furthermore, the same result can be obtained if one were to demand that the condition of isotropy be fulfilled not only locally, but also integrally, in the scales of the entire space.) Fridman investigated uniform isotropic models with a space of negative curvature (Lobachevskiy space) filled with dust matter. These models also turned out to be possible when the cosmologic constant was positive, negative and equal to zero. The types of their behavior were reduced to certain types of behavior of models with a space of positive curvature (see the case $k = -1$, types M_1 and O_1). The static model, analogous to the model of Einstein, turns out to be impossible. At the same time an empty static model, analogous to the model of de Sitter turns out to be possible (we call it the de Sitter-Fridman model). Obviously, Fridman's results demonstrated that the Einstein equations do not lead to a single model of the universe, no matter what the cosmologic constant.

It is easy to see that the simplifying assumptions kept or accepted by Fridman mean the behavior and properties of the cosmologic model (for any given value of the cosmologic constant) are completely determined by one function of time and sign of the curvature of space. Study of the universe by construction and comparison with astronomical observational data of such simplified models Fridman considered as

forced because the path which he recognized as ideally correct is inapplicable practically in view of the involved mathematical difficulties and insufficiency of available astronomical data. Fridman saw this as a means to examine different particular solutions of Einstein's equations, consisting of a system of ten functions of four coordinates (i.e., the biggest number which can be found from these equations), and to compare them with data of astronomical observations. But any solution consisting of so great a number of functions of four coordinates, describes the very general case of an anisotropic nonuniform universe. Therefore it is possible to say that essentially A. A. Fridman was not only the founder of the contemporary theory of a nonstationary uniform isotropic universe, but also the first to pose the problem of constructing a theory of an anisotropic nonuniform universe. Moreover, he supported exactly this last theory. The views of Fridman briefly described here unfortunately are comparatively little-known, since they were expounded by him only in his popular book.

The results of Fridman were reflected in the work of other Soviet authors. Thus, V. K. Frederiks and A. B. Shekhter (1928) examined aberration and parallax in the models of Einstein, de Sitter and Fridman. M. V. Machinskiy (1929) examined the possibility of finiteness and infinity of space for the same positive curvature and the observational indistinguishability of these two cases.

4. If the creation of a general theory of relativity independently of the detection of a metagalactic red shift led to relativistic cosmologic models, at first stationary and then nonstationary, the discovery of the world of galaxies promoted development of the theory of hierarchy, structure of the universe, about which we already mentioned and to which we will return later. Here we note only that the work developing this theory appeared in Sweden (C. V. L. Charlier) and Austria (F. Sheleti [Translator's Note: exact spelling not found] in 1922, i.e., almost simultaneously with the first work of Fridman. This theory made it possible to interpret the high speeds of galaxies, but could not explain either the predominance of red shifts over violet and their increase with distance, which was possible within the bounds of the de Sitter model without additional hypotheses, which



essentially signified transition to the theory of the nonstationary universe. Discovery and investigation of the red shift stimulated in the West interest toward this theory. The work of Fridman, especially his models of the space-infinite universe, was forgotten, and some of his results were obtained again by other authors. Unfortunately, Fridman's work was repeatedly ignored even after his priority was restored, and his results obtained world acknowledgement.

The works of other authors not only repeated, but also supplemented Fridman's results. Thus, Lemaître, instead of dust matter introduced into consideration matter producing pressure, which permitted considering the presence of radiation and peculiar speeds of galaxies. O. Heckmann and G. Robertson along with cases of positive and negative curvature examined also the case of curvature equal to zero, i.e., a Euclidean space. Calculation of positive pressure, increasing or diminishing together with (positive) density, does not change the types of behavior of models. Types of behavior of models with zero curvature of space are the same as for models with negative curvature (see the figure, case $k = 0$, types M_1 and O_1). (In all cases R is the

"scale factor," and k/R^2 the curvature of space, where $k = 0, \pm 1$; thus, $k \neq 0$ R is equal to the radius of the curvature of space.)

As for Eddington, first time from the equations of Fridman instability of the model of Einstein beoomes evident. Its stationess is caused by the equilibrium between forces of gravitational attraction of masses and the cosmic forces of repulsion. An arbitrarily small increase of density everywhere in the model leads to its unlimited compression, whereas an arbitrarily small lowering of density everywhere leads to unlimited expansion of the model (see the figure, type A_2). It becomes understandable also why Einstein's model is inconveivable without masses: they are necessary in order to balance the cosmic repulsive forces by the forces of gravitational attraction.

K. Lantzosh, G. Lemaître and G. Robertson examined the de Sitter model in different nonstatic freely incident reference systems satisfying requirements of homogeneity and isotropy. These systems of reference are distinguished in behavior with time and in curvature of space: in the Lantzosh system it is positive, in the Lemaître system equal to zero, and in the Robertson system negative (see the figure on p. 435, cases $k = +1, 0, -1$, type S). The de Sitter-Einstein model earlier was examined in a static system of reference (see the figure, case $k = 0$, type SE), as well as the de Sitter-Fridman model (SF) by Robertson in nonstatic freely incident systems of reference, satisfying requirements of homogeneity and isotropy and possessing a space of negative curvature (see the figure, case $k = -1$, types SE and SF correspondingly). In the same way the de Sitter, de Sitter-Einstein and de Sitter-Fridman models, in which average density of mass is equal to zero, belonged to the number of uniform isotropic nonstatic models.

The model of de Sitter in nonstatic systems of reference turned out to have no special (singular) points, which showed the illegality of considering a horizon of the de Sitter model (see above) as manifestation of the presence of mass, distributed with infinite density, and the validity of treating this model as deprived of

masses. Essentially, this circumstance solved the question about the material postulate of relativity of inertia in favor of its apponent, although it still has supporters.

Development of the theory of a uniform isotropic universe was, of course, not limited to finding all permissible (from the point of view of general physical concepts of density of mass and pressure) models of such a universe and investigation of the types of behavior. Relativistic thermodynamics, developed by the American physicist R. Tolman, was applied by him to uniform isotropic models. The theory of observable effects, in other words the theory of comparison of these models with observational data of extragalactic astronomy, was developed by R. Tolman, E. Hubble, G. Robertson and other authors.

In cosmologic models matter is examined as a continuous medium, at rest with respect to space and expanding or contracting together with it. In the first years of relativistic cosmology such "motion of matter together with space" was examined as something different from "motion of matter in space." However, later came the opinion that both forms of motion coincide essentially and are distinguished only by the method of description. "Motion together with space" constitutes the usual motion described in the so-called accompanying system of reference, in which by definition the velocity of matter is everywhere zero, i.e., in a system of reference moving together with matter. Moreover, in the general theory of relativity the motion of matter is examined without the help of equations of motion by means of only some equations of a field of gravitation. The possibility of considering motion without equations of motion is a peculiarity of the general theory of relativity, inasmuch as in it equations of motion in a field, as was clarified by Einstein and Grommer in 1927, are contained in equations of the gravitational field. (Curiously, this peculiarity was not noticed earlier, although it follows from the circumstance that equations of a gravitational field, in accordance with the requirement established by Einstein during their formulating, contain the laws of conservation of energy and momentum.) Thus, the work of Fridman actually for the first time used accompanying systems of reference and considered the motion of matter without equations of motion — using only some field equations.

5. Fridman, apparently not having information about the metagalatic red shift, at least during the time of his cosmologic work, considered that without exception all conclusions obtained from theoretical study of the universe by means of uniform isotropic models, should be regarded with distrust. This opinion turned out to be too pessimistic. From the theory of a uniform isotropic universe it follows that during expansion a red shift should be observed in proportion to distance. (Calculation of peculiar galactic speeds and solar motion in the galaxy due to the rotation of the latter made it possible to explain the violet shifts observed in the spectra of several of the nearest galaxies.) Since the proportionality factor did not show a noticeable dependence on direction, and the distribution of galaxies in space is disorderly, uniform isotropic models were now examined as reflection of properties of the real universe, not only in a certain limited region of space on a certain limited interval of time, but in all regions of the universe and in all epochs of its existence. Thus, the theory of a uniform isotropic universe began to be examined not as a very approximate, rough theory of the world enveloped by observations, useful for its description in a certain epoch, but as a theory of the universe as a whole. However, this was excessive optimism.

The investigation of uniform isotropic models is the first phase relativistic cosmology. Simplification of these models assumes that the properties and behavior of every element of the universe do not depend on direction (isotropy) and in any given instant the properties and behavior of all elements of the universe are identical (homogeneity). Here by element one should understand a region small as compared to the actually observed part of the metagalaxy, but containing a sufficiently great number of galaxies. Further, the simplification peculiar also to a more general class of conceivable models consists in disregarding local (inside every element) heterogeneity of the universe. Finally, the limitedness peculiar to cosmology, founded on the general theory of relativity, consists in the fact that the latter is not the most general physical theory with which, in particular, is connected possibly the actual fact of multiplicity of models of the universe allowed by it.

Already on the first phase of relativistic cosmology it turned out to be possible to remove the basic difficulties which met nonrelativistic cosmology. Really, Einstein's theory of gravitation does not know the gravitational paradox peculiar to the Newtonian theory of gravitation, i.e., the conclusion according to which the latter without additional requirements does not lead to simple finite values for the forces of gravitation when the density of mass averaged over all space is not equal to zero. Now uniform distributions, belonging to the number of those which in nonrelativistic cosmology let to the gravitational paradox, turn out to be nonstationary. The photometric paradox is removed by calculation of the metagalactic red shift, which reduces the surface brightness of radiating objects. The idea of "thermal death" of the universe is eliminated, even without appealing to the fluctuation hypothesis, in view of the absence for a gravitational universe of a defined state of maximum entropy.

However, this phase of relativistic cosmology also has inherent difficulties which can be removed by the further development of cosmology. In the first difficulty, having fundamental character and essentially not new (since it is inherent to prerelativistic cosmology), the already mentioned multiplicity of models of the universe. The second is that solutions to the Einstein equations for uniform isotropic models of the universe have a physical meaning on an interval of time bound from one (see types A_1 and M_1) or from both sides (see type O_1). The boundaries of this interval are the so-called special states or simularity, in which the scale factor turns into zero, and the rate of its change, density of mass and (if the medium is not dust) pressure turn into infinity. The only exception is certain models with positive cosmologic constant (see types A_2 and M_2). In all models in which expansion is not changed by compression, the proximity of departing galaxies observed in the contemporary epoch obviously is not repeated in other epochs. A third difficulty is that for those models whose expansion starts from singularity, the time from the beginning of expansion turns out to be although of the same order as the age of the oldest objects in outer space, still two or three times less. The fourth difficulty is the presence of inexplicable empirical relationships between microphysical constants, on one hand, and metagalactic parameters (average density of mass in metagalaxy and the Hubble parameter,

i.e., proportionality factor in dependence of speed of removal of galaxies on their distance) on the other. Inasmuch as metagalactic parameters must change in time, and the microphysical constants must remain constant, this connection turns out to be the privilege of only the contemporary epoch, for which it is impossible to find a reasonable explanation.

The first of the difficulties, as was already noted, is irremovable within the bounds of existing physical theories. The second and third difficulty in principle are removed by rejecting the hypothesis of homogeneity and isotropy. Probably, but not reliably, the same is true with respect to the fourth difficulty.

All these difficulties promoted abroad the appearance of new cosmologic theories, in which the requirements of homogeneity and isotropy were preserved, but the general theory of relativity either was subjected to supplements or generalizations, or was completely rejected. In particular, the fourth of the difficulties brought Dirac to the idea of changeability of certain world constants, where the idea of two scales of time was used: in one of them microphysical constants are variable, in the other – the gravitational constant.

In the history of cosmology besides the enumerated difficulties, two others which turned out to be fictitious played an important role. One of them was that in the first years of existence of relativistic cosmology in cosmogony an estimate of the ages of stars and galaxies of the order of a thousand billion years predominated ("long scale"), which could not be reasonably reconciled with a duration of expansion of the order of several billion years ("short scale"). This contradiction led to the appearance of the kinematic theory of relativity and the kinematic cosmology of Milne with its two scales of time. The lack of grounding for the "long scale" became clear as a result of three discoveries: rotation of the galaxy (J. Oort), peculiarities of statistics of gravitational systems (V. A. Ambartsumyan) and the theory of nuclear reactions in stars (H. Bethe). Another difficulty was the impossibility of coordinating the requirements of the relativistic cosmologic theory with data from extragalactic

astronomy during attempts to determine on the basis of these data the curvature of space (1936). This difficulty was rooted partly in the roughness of the cosmologic models themselves, and partly in the insufficiency and inaccuracy of data from observations, i.e., essentially, in the same causes which caused the sceptical relation to the theory of a uniform isotropic universe from its founder.

6. The task of synthesis of a general theory of relativity and of a quantum theory does not belong to the number of problems of cosmology, but has an essential value for it, since a solution to this problem would give to cosmology a new, more general physico-theoretical basis. The first attempt at such a synthesis, although only for weak models, was made by the Soviet physicist M. P. Bronstein (1906-1938): he proposed the first quantum theory of gravitational fields (1936).

Before the hypothesis of the neutrino, N. Bohr expressed an idea according to which in the relativistic quantum theory the laws of conservation of energy and momentum lose force, and proposed a hypothesis of the generation of energy in the interior of stars founded on this idea. A variant of the cosmologic theory, phenomenologically considering the hypothetical process of the appearance of energy, was proposed by Bronstein (1933). The fundamental equations in this variant are the equations of Fridman (in other words, Einstein's equation for the case of a uniform isotropic universe), but with a cosmologic constant which is monotonically time-dependent. It is necessary, however, to note that in such a description the appearance of energy is equivalent to the transformation of certain reintroduced hypothetical form of energy into known forms with fulfillment of the laws of preservation. Regarding, the idea of nonconservation of energy and momentum, as it is known, in physics it was abandoned with the appearance of the hypothesis of the neutrino. However, the connected idea that the history of the universe is asymmetric with respect to past and future, is only a praticular variant of the more general ideas of L. D. Landau, developed by him jointly with Bronstein and other authors.

As it is known, statistical treatment of thermodynamics negates the "thermal death" of the universe in nonrelativistic physics as

well, allowing treatment of the behavior of the part of the universe enveloped by observations as fluctuation during statistical equilibrium of the universe as a whole. However, such treatment is not very satisfactory, inasmuch as it leads to an extraordinarily small probability of the observed picture of the world. This last consideration is usually removed by reference to the fact that the absence of observable gigantic fluctuation (in a volume not smaller than the whole known part of the universe) is necessary for the appearance of living beings, observing the developing picture of the world, and that consequently, the a posteriori probability of the observed picture of the world in the presence of living beings is equal to (or close to) unity. According to Landau, this last argument is wrong. The fact is that the probability of fluctuation in the volume observed by us is startlingly small as compared to the probability of much smaller fluctuations (i.e., fluctuations in smaller volumes), already sufficient for the possibility of life, observing the picture of the surrounding world: considering independence of fluctuations the ratio of their probabilities is inversely proportional to the ratio of the volumes enveloped. This shows an inconceivably small a posteriori probability of the picture of the world observed by us from the point of view of the fluctuation hypothesis and, consequently, just as unsatisfactory an explanation of this picture of the world with the help of this hypothesis. (Subsequently these conclusions encountered objections, to which we will return later.)

What was said indicates the difficulty of coordinating the asymmetry of the observed behavior of the universe (more exactly, the known part) with respect to the past and future with requirements of statistical theory, founded on the laws of mechanics, which do not possess such asymmetry. According to Landau, this difficulty should be explained by the fact that in the universe processes not obeying these laws at the basis of statistical mechanics take place, and that therefore the universe as a whole does not obey.

L. D. Landau and Ye. M. Lifshits (1951) expressed an idea according to which the unequivalent character of two directions of time is rooted in quantum-mechanical regularities, in spite of the

fact that fundamental equations of quantum mechanics, as for other known basic physical theories, are symmetric with respect to the past and future. Actually, if the quantum-mechanical system in two different, following instants experiences interaction with systems which can be considered as classical, the result of the preceding (in time) interaction determines the probability of subsequent interaction, but not conversely. In the opinion of the cited authors, there should exist a still undiscovered connection between this quantum-mechanical regularity and the second beginning of thermodynamics.

7. Interpretation of the metagalactic red shift on the basis of the Doppler principle seemed natural, inasmuch as this shift possesses a feature inherent to only the Doppler effect and the Einstein effect: $\Delta\nu/\nu$ is identical for all lines of the spectrum of the same source. However, partly in view of the dissatisfaction with the cosmologic models, soon after establishing the monatonic dependence of the red shift on distance assumptions were made of the non-Doppler character of this shift. One of the first assumptions of this kind was made by A. A. Belopol'skiy (1929). He assumed that the frequency of the photons changes with their motion in space in inverse proportion to the distance passed. However, no physical explanation to such fall of frequency was given. Other assumptions were expressed. Such, for example, was an attempt to examine the metagalactic red shift as gravitational, i.e., as an Einstein effect (A. A. Treskov, 1932). It is possible, however, to show that in this case the monotonic dependence of shift on distance and the presence of shifts of only one sign would be the privilege of only one point of space and, consequently, would signify a provileged (central) position of our galaxy in the universe. But also in this case it would have been possible to explain a violet shift, but not a red. Among other explanations abroad a hypothesis was expressed by which the metagalactic red shift is the result of spontaneous disintegration of photons, equivalent to light scattering on a Dirac background of electrons. Refuting this hypothesis, M. P. Bronstein showed (1936) that during spontaneous disintegration of photons for all lines of the spectrum of the same light source not $\Delta\nu/\nu$, but $\Delta\nu$ would be identical, which as is well known, contradicts facts. Furthermore, the probability of this disintegration turned out to be equal to zero.

In 1938-1940 the Soviet astronomer A. F. Bogorodskiy tried to explain the metagalactic red shift by loss of energy by a photon under the impact of its own gravitational field, proceeding from the coincidence of speeds of photons and propagation of gravitational interaction. He obtained the approximate proportionality of red shift to distance, but the question about the theoretical value of the proportionality factor remained open. In 1945 under the influence of the discovery of the Cherenkov glow Soviet physicist L. M. Brekho Brekhovskikh examined the possibility of loss of energy by electromagnetic waves propagating in relativistic uniform isotropic models of the universe by the radiation of gravity waves. He concluded that such an effect exists, but is too weak to explain the observed red shift.

From time to time in various variants the idea of explaining the metagalactic red shift by light scattering on some particles is discussed. But it is absolutely obvious that such scattering would lead not only to a lowering of the frequency of light but also to considerable lowering of the quantity of light propagating in the former (initial) direction, i.e., to its extinction. It would be stronger than larger the value of displacement (so that a galaxy with a very great red shift could not be observed). However, there is nothing similar. Much rarer is the assumption of the possibility of explaining the metagalactic red shift by transverse Doppler effect. But if such an explanation would be correct, our galaxy would be in the center around which other galaxies would turn on their orbits, lying in a disorderly array of oriented planes. Besides, since metagalactic density does not depend on distance, the value of displacement had to be in the first approximation proportional to the square of the distance from our galaxy, which, as is known, contradicts observations. This contradiction will hold also if we assume that galaxies turn on orbits lying in parallel planes around the axis on which our galaxy lies. Now one more contradiction to facts will be added, since very strong anisotropy of the red shift would have to be observed it would be the biggest in directions perpendicular to the axis, and would be absent in the direction of the axis.

Thus, longitudinal Doppler effect remains the only known physical phenomenon with which it is possible to explain the observed metagalactic red shift or, in any case, the predominant part determining its characteristic features: 1) independence of $\Delta\nu/\nu$ from ν in the spectrum of any given light source (galaxy); 2) for galaxies, visible in the nearest directions but at different distances, in the first approximation – proportionality of $\Delta\nu/\nu$ to distance; 3) for galaxies visible in any directions – absence of strong dependence of proportionality factor (between $\Delta\nu/\nu$ and distance) on direction, i.e., approximate isotropy.

Obviously, all other physical phenomena used to explain the metagalactic red shift both hypothetical and real, do not achieve their purpose. They either do not lead to a red shift, or cannot explain its characteristic features or lead to too weak an effect, or, finally, must cause together with a red shift such side phenomena which in reality are not observed.

It is necessary to note from the point of view of Einstein's theory of gravitation the Doppler and Einstein effects are special cases of the so-called generalized Doppler effect. Strictly, Doppler effect in turn is made up of shifts caused by the motion of the source and receiver with respect to the selected system of reference, and shifts conditioned by deformation of the actual system of reference during the time of propagation of radiation from source to receiver. For a given source and receiver the total shift, of course, does not depend on the selection of the system of reference, but splitting of the shift into different components of its effect essentially depends on this selection. In uniform models in the accompanying system of reference the Einstein effect is equal to zero, but the Doppler effect – if source and receiver are at rest in this system – leads to a shift induced by its deformation in time.

Interest toward non-Doppler interpretations of the metagalactic red shift apparently intensified twice – after the monotonic dependence of this effect on distance was established (1929) and after the failure of attempts to determine the curvature of space on the basis of

observational data of extragalactic astronomy and coordination of the obtained value of curvature with requirements of uniform isotropic models (1936).

8. Non-Doppler interpretation of the metagalactic red shift was by no means the only alternative to interpretation of this phenomenon with the help of relativistic cosmologic models. Attempts were made to construct a theory of a limited expanding metagalaxy outside which an infinite number of other metagalaxies can exist. The first such theory was constructed in 1932-1934 by the Soviet astronomer M. S. Eygenson. According to this theory our metagalaxy is made up of a finite cluster of galaxies turning around its center. Removal of galaxies is examined as the result of an increase in the dimensions of their osculating orbits, induced by a weakening of their attraction to the center due to a secular decrease of the mass of all galaxies. The theory left open the question about the mechanism for the decrease of mass, since the only reliably known process causing a decrease of the mass of galaxies - radiation of light by stars - leads to a theoretical value of the mentioned coefficient much (three orders) smaller than the observed.

Another hypothesis which also assumed limitedness of the metagalaxy and the existence outside it of other metagalaxies was proposed in 1935 by V. A. Krat. According to this hypothesis the expansion of the metagalaxy was preceded by its compression, induced by the formation condensation. It is assumed that expansion was caused by a decrease of mass due to the starting process of radiation, but with a weakening of gravitational attraction it became almost purely kinematic, leading to a scattering of the galaxies. Along with this process is assumed the formation of metagalaxies by reconstitution of the matter from radiation (the law of preservation of the baryon number still was not known). A drop in the frequency of photons is allowed also (according to Belopol'skiy) as one of the causes of the red shift. To describe the process of expansion of the metagalaxy is used a relativistic model of a uniform isotropic universe (i.e., it is assyned that such a model is applicable to a description of not the whole universe but a limited system in it).

9. A special case of the hypothesis of the limitedness of our metagalaxy and the existence outside it (and besides an infinite number) of other metagalaxies is the theory of the heirarchy structure of the universe. According to this theory distribution of masses in the universe constitutes an infinite sequence of systems of orders of i from $i = 0$ to $i = \infty$, where every system of the order $i + 1$ consists of a certain number of systems of order i, and by systems of zero order ($i = 0$) are understood the stars. Here on the dimensions and mass of the systems are superimposed limitations ensuring removal of the photometric and gravitational paradoxes. The meaning of these limitations is to ensure sufficiently rapid tendency to zero of the average density of systems considering unlimited transition to systems of an ever higher order. This theory, developing an idea of Lambert, was developed in 1908 and 1922 by Charlier and in 1922 also by Sheleti, who, in particular, examined the hierarchy structure from the point of view of statistical mechanics. He showed that a system of any order $i + 1$ must with time lose a component system of order i and thus disperse. Sheleti also developed a theory of hierarchy structure within the framework of Einstein's theory of gravitation. The hierarchy model of the universe was considered as a variant of the de Sitter-Einstein static model ($k = 0$, type SE) with infinite mass.

The peculiar speeds of systems of order i in a system of order $i + 1$ must be greater the higher this order is. This could explain the high speeds of galaxies, but could not explain the presence of only positive speeds and their monotonic dependence on distance, which resulted in a fall in interest toward this theory. Interest toward it increased only after 1936 in connection with doubts of the applicability of uniform isotropic relativistic models to the actual universe and simultaneously with attempts of non-Doppler interpretations of the red shift.

V. G. Fesenkov posed the question about dimensions of a uniform sphere in the center of which objects in it would impart to the sky surface a brightness equal to that observed, corrected for the influence of intragalactic sources. Disregarding the influence of the red shift on the brightness of light sources (which corresponds to an assumption of local kinematic character of the red shift) it was

found that these dimensions only exceed the dimensions of the region enveloped by observations of that time by 20 times. Coming thus to the conclusion of the limitedness of our metagalaxy, V. G. Fesenkov passed to consideration of the hierarchy structure of Charlier. But the Charlier scheme did not consider the influence of dark matter on the luminosity of the sky. Meanwhile from the above work of V. G. Fesenkov (1918) it appeared that the presence of dark matter does not facilitate, as had been thought, but hampers the position. A new solution to the question, refuting views ruling earlier, was given by V. G. Fesenkov in 1937. By assuming pure scattering (without absorption) and calculating scattering of all orders it was shown that dark space matter, repeatedly dispersing the light radiated by stars, plays the role of its accumulator and thus increases luminosity (night) of the sky in a given cosmic system more strongly the larger its optical thickness. By disregarding the extent of light sources (stars) it was found that for an unlimited increase of optical thickness of a system the luminosity of the sky in scattered light increases without limit.

V. G. Fesenkov generalized the Charlier scheme by considering the dispersing matter. In the generalized scheme a system of any order i + 1 consists, in general, not only of systems of order i, but also of dispersing matter continuously distributed between them, which obviously is much nearer to reality than the initial Charlier scheme. By applying the obtained results to the generalized scheme, Fesenkov showed that removal of the photometric paradox in the presence of dispersing matter (assuming pure scattering and disregarding the influence of the red shift) requires limitations on the distribution of dark matter over the usual limitations peculiar to the initial Charlier scheme. These additional limitations require nongrowth (or decrease) of the optical thickness of systems with an increase of their order. Under the assumption of identical character of dark matter in systems of all orders these limitations must obviously be fulfilled in conditions analogous to those put on the distribution of radiating matter: the product of the average density of matter in a system by its radius (if one assumes it to be uniform and spherical) should drop out upon transition to systems of an ever higher order. (Now, as is

easy to show, removal of the gravitational paradox may be also ensured.)

Later Fesenkov indicated an artificial character of the theory of an infinite hierarchy structure in general. Let us note that such a structure can only exist from an age and continuously be destroyed, but cannot be recreated. But, of course, the value of a new approach to the role of dispersing matter in creating the luminosity of the night sky and to clarification of the structure of the universe by this luminosity goes beyond this theory.

The same is true of the idea of a "pyramid of scales" (time scales are considered), advanced in 1938 by V. A. Ambartsumyan, and of his statistical and mechanical investigations. According to this idea the age of a system of the order of i + 1 should exceed the age of the systems composing it of order i; in other words, the higher the order of a system, the longer its time base should be. Such a relationship of bases is necessary to preserve the structural-scale stairs and the possibility of developing a system of the lowest order under the effect of its internal in the system of higher order. This idea was in its time contrasted with another, according to which the duration of expansion of the universe as a whole is measured by billions of years ("short scale"), whereas for the evolution of galaxies and stars periods of the order of thousands of billions of years are characteristic ("long scale"). (It was attempted to coordinate such a relationship of scales with the relativistic cosmologic model type M_2.) The statistical-mechanical investigations of Ambartsumyan played an essential role in proving the untenability of the "long scale."

Advancing his idea of the "pyramid of scales," Ambartsumyan indicated that with respect to already known astronomical steps of the structural-scale stairs this idea will agree with data of astronomy. When statistical mechanics is applicable to systems of adjacent orders, this idea will agree with statistical-mechanical conclusions obtained by V. A. Ambartsumyan related to gravitational systems. Namely, in this case the relaxation time of a system of order i + 1

should exceed the relaxation time of a system of order 1 (or in the extreme case equal it). This conditions, as also the actual idea of a "pyramid of scales," is not connected necessarily with the theory of an infinite hierarchy structure and goes far beyond it.

10. The possibility of freeing the theory of an infinite hierarchy structure from the limitations imposed for removing the photometric and gravitational paradoxes was examined in 1938-1940 by M. S. Eygenson. For removing the photometric paradox just as in relativistic cosmology the metagalactic red shift was considered. The question about the effect of a shielding of the sky by luminescent objects in connection with luminosity of the sky in the Charlier model was examined in 1940 by Gordon.

In connection with the attempt to remove the gravitational paradox without the limitation of an infinite hierarchy structure Eygenson formulated his prinicipls of the "autonomy" of systems as a necessary condition for the stable existence of structural-scale stairs. The "autonomy" of a system by definition means that motions inside it are determined mainly by the field created by it and do not depend essentially on the field of force of higher order systems containing it.

The theory of infinite hierarchy structure has for nonrelativistic cosmology a specific value, since only it, under limitations of the "Charlier-Fesenkov" type permits removing within the bounds of nonrelativistic physics the photometric and gravitational paradoxes without physically groundless assumptions. This theory is connected with the assumption according to which the average density of mass over all space is equal to zero. As is known, relativistic cosmology can remove both paradoxes even without this assumption (more exactly, it removes easily the photometric paradox and is free from the gravitational paradox). However, this theory was also examined (F. Sheleti, 1922) within the bounds of relativistic cosmology. M. S. Eygenson (1940) noted that the physical autonomy of a system in this case signifies the presence of an essential dependence of space-time metrics in the scales a given system on distribution and behavior of

masses mainly in its limits. Not only the density of mass, etc., but also the properties of the metrics depend on the order of the system in whose scale these values and properties are examined (principle of "cosmologic relativity"). Later (1954) M. S. Eygenson formulated other principles for the infinite hierarchy structure, first of all the principle of "cosmologic" atomicity, which confirmed the discreteness of structure of systems of all orders. G. M. Idlis (1956) formulated the condition of autonomy for a hierarchy structure consisting of uniform spherical systems. Combining the nonrelativistic relationship between mass and energy, and considering that the energy of a field of gravitation of any system is negative, Idlis concluded that the gravitational paradox, more exactly the part of it which touches on relative accelerations, is absent in any infinite hierarchy structure.

It is clear from a logical point of view that the combination of the Newtonian law of gravitation with the relativistic relationship between mass and energy contains an internal contradiction, inasmuch as according to the Newtonian law of gravitation the propagation velocity of gravitational interaction is infinite, and the relativistic relationship between mass and energy contains a fundamental speed — the finite terminal velocity of the propagation of interaction.

Nonetheless this contradiction can be by passed if, using the relativistic relationship in nonrelativistic theory fundamental speed is examined only as a constant and its interpretation as the terminal velocity of the propagation of interaction is rejected.

The photometric paradox usually was examined either for the bolometric brightness of the sky, or for its brightness in optical radiation. After the discovery of cosmic radio emission it was clarified that a difficulty analogous to the photometric paradox also exists for this radiation. This "photometric paradox" for radio emission was formulated by I. S. Shklovskiy (1954). He used a new approach concerning this paradox, applied by V. G. Fesenkov, namely the comparison of observed brightness of the sky with the brightness created by sources in the region of the universe enveloped by

observations. Shklovskiy found that in contrast to optical radiation radio emission the the galaxies in this region had to - if there were no weakening factors - impart to the sky a brightness (in radio frequencies) exceeding that observed. From this conclusion it followed that the photometric paradox for radio emission cannot be removed no matter what assumptions are made about the distribution of masses (more exactly, sources of radio emission) outside the region enveloped by observations, for example, an assumption of hierarchy structure of the Charlier type. Shklovskiy arrived at a conclusion according to which consideration of the metagalactic red shift assuming its Doppler nature and making certain assumptions on its dependence on distance permit removing the paradox, whereas the hypothesis of power degradation of photons (i.e., loss of energy) is insufficient for its removal. (It was known that the Doppler red shift weakens the brightness and luminance of light sources more strongly than the non-Doppler red shift.)

Knowing that consideration of the red shift does not completely remove the photometric paradox for radio emission, G. G. Getmantsev (1956) examines the possibility removing it by assuming that the radio radiating ability of metagalactic sources in the past was relatively small.

11. We already said that Einstein's theory of gravitation permits studying the motion of a continuous medium without equations of motion, by means of some (and only) equations of the field of gravitation written in accompanying coordinates, and that in this is the meaning of expansion (or compression) of matter "together with space" described by cosmologic models, although this was not yet known to Fridman. We said also that the actual possibility of such a method of study motion is rooted in the fact that Einstein's equations of a gravitational field, expressing the law of gravitation, contain also the law of motion in a gravitational field, — a fact discovered by Einstein and Grommer after the death of Fridman. (Let us note that at the time of the discovery of this fact it still was not established in connection with cosmologic models and the meaning of the expansion of matter "with space" was comprehended later.)

Hence followed the possibility of deriving equations of motion from field equations. Such a derivation approximate equations of motion was given in 1938 by Einstein, Infeld and Hoffman. Moreover, agreeing with the idea of Einstein, matter was examined as special (singular) points of a gravitational field.

V. A. Fok (1939) independently gave another derivation of equations of motion from field equations. Masses were examined not as point peculiarities, but as extended bodies, which, of course, gives a more correct reflection of reality. Such consideration permitted considering both the physical state of bodies and its influence on their motion. Later N. M. Petrov continued this work, examining the subsequent approach. One peculiarity of this work of V. A. Fok and N. M. Petrov and one of the results of the first connects them with one of the fundamental problems of Einstein's theory of gravitation. The fact is that in these works used so-called harmonic coordinate systems, first introduced in the gravitational theory of Einstein, apparently, by Lantsosh (1922). Harmonic coordinates are remarkable because in them Einstein's equations can be given the form of generalized wave equations, and besides in relation to all ten components of the fundamental tensor (in arbitrary coordinates Einstein's equation in general contain second order derivatives only from six components). But in that conncection in which these coordinates interest us now still more important are their other peculiarities. First, they constitute a generalization of so-called Galilean coordinates of a special theory of relativity (i.e., rectilinear space-time coordinates of inertial systems of reference); secondly, all coordinate systems connected by linear transformations with any harmonic coordinate system also will be harmonic systems, which still more relates harmonic systems with inertial. However, in general it is impossible to affirm that any two harmonic systems are connected by linear transformations, and this disturbs the similarity of harmonic systems with the inertials. But, as Fok indicated in the cited work, this distinction of harmonic systems from inertial is absent in the case of such distributions of masses with which space-time metrics on infinity is Galilean (i.e., on infinity space-time in its geometry constitutes a work of a special theory of

relativity). For this it is necessary that the density of mass sufficiently rapidly tend to zero as it goes into infinity. Obviously when the distances of the mass whose field we examine from other masses are sufficiently great as compared to its dimensions (as, for example, distances between stars in the galaxy are great in comparison with their dimensions), all harmonic systems are connected either by linear transformations, or differ sufficiently little from linear.

Thus, at least for certain distributions of masses there exist preferential systems of reference analogous to inertial systems of a special theory of relativity and constituting their generalization. This circumstance was shown by Fok as an argument against understanding Eninstein's theory of gravitation as a theory of general relativity and against its name - general theory of relativity. Discussion concerning this question flared later. Now we note only the following curious circumstances, by no means accidental. First, if an empty world theoretically is possible, then distributions leading to Galilean metrics on infinity are possible, and, consequently, the above preferential systems of coordinates are possible. Conversely, if these systems of coordinates are possible, then Galilean metrics on infinity is possible, and then an empty world is possible. Thus, the absence of general relativity in the sense of V. A. Fok is equivalent to nonfulfillment of the material postulate of relativity of inertia. Secondly, if a hierarchy structure with zero density of mass averaged over all space theroetically is possible, then an empty world is possible also. Conversely, if an empty world is possible, then the shown structure is also possible. Thus, the possibility of such structure is equivalent to the absence of general relativity in the sense of Fok and nonfulfillment of the material postulate of relativity of inertia.

12. It is well known that Einstein's law of gravitation, expressed by the equations bearing his name emanates from the general principles of his theory of gravitation only under certain additional assumptions. The mentioned general principles require only that the law of gravitation be general and covariant, be expressed by a system of ten partial differential equations relatively to ten components of

the space-time fundamental tensor and satisfy laws of conservation of energy and momentum (from these laws follow the equations of motion). All these requirements will be carried out if one obtains the left sides of the equation by means of a certain variational principle, using as the Lagrangian any fundamental invariant, i.e., an invariant built only from the fundamental tensor and its derivatives. In such a way we can obtain a set of gravitation laws. But among them will be only one, expressed by second order equations which is Eninstein's law of gravitation (in general, with a cosmologic constant), whereas other laws are expressed by equations at least the fourth order. Thus, to obtain simply the Einstein equation it is necessary to introduce the additional requirement that the order of equations of the field of gravitation should be second or lower than fourth, or some other equivalent to it.

In 1940-1941 A. F. Bogorodskiy developed a new general method of deriving laws of gravitation, satisfying the basic requirements of Einstein's gravitational theory. This method does not appeal to the variational principle and is based on application of the apparatus of covariant integration. For Riemannian spaces of two and three dimensions such an apparatus was worked out by Ya. S. Dubnov. A. F. Bogorodskiy generalized it in the case of four dimensions. The order of field equations was not studied.

13. The problem of the formation of thickenings developing into different cosmic bodies and systems turned out to be one of the most difficult in relativistic theory. In any variant of the theory of a uniform isotropic universe, the formation of cosmic bodies and systems pertained to some definite time in the past; in models of type M_1 (with one exception) and O_1, expanding from singularity to a time when density had to be of nuclear order, and somewhat later, in a model of type M_1 when $\Lambda > 0$, $k = +1$ – to an epoch close to passage through the state of the E model (epoch of almost nonaccelerated expansion); in a model of type A_2 – to the epoch of the beginning of expansion. Facts witnessing that the formation of cosmic bodies and systems is occurring even this epoch did not fall within these concepts and served as a new basis for revamping or rejection of Einstein's

theory of gravitation as the basis of cosmology - preserving the hypotheses of homogeneity and isotropy. Later the idea crystallized in which continuing formation of objects in outer space occurs either from thickenings appearing earlier, or from diffuse matter generated earlier by the objects which were forming. Revision or rejection of Einstein's theory of gravitation in cosmology to remove difficulties in the formation of a condensation was never used in the Soviet Union, but the problem itself, belonging more to cosmogony than to cosmology, was given considerable attention.

The formation of a condensation usually is connected with the theory of gravitational instability. This theory, worked out by J. Jeans within the bounds of Newtonian physics, in the Soviet Union was developed starting from 1938 by A. B. Severnyy, and later L. E. Gurevich and A. I. Lebedinskiy and other authors. Gravitational instability within the bounds of Einstein's theory of gravitation was considered by foreign authors, who posed this problem in reference to models of types A_2 and M_1 for $\Lambda > 0$, $k = +1$. G. Gamov and E. Teller (United States, 1939) examined the same problem in reference to models corresponding to $\Lambda = 0$. However, their consideration was, first, inconsistent, inasmuch as they without any justification applied to a relativistic expanded model a nonrelativistic criterion of gravitational instability, formulated for stationary distribution, and, secondly, it was mathematically incorrect since it contained a logical contradiction.

These critical remarks were published in 1947 by A. B. Severnyy and the author. But during this time a correct, consistent relativistic investigation of the gravitational stability of a uniform isotropic universe already was known (also for $\Lambda = 0$), belonging to Ye. M. Lifshits (1946). He examined perturbations of different types: perturbations with a change of density, field of speeds and metrics; perturbations with a change of only the field of speeds and metrics and, finally, perturbations with a change of only one metrics. It was shown that upon expansion perturbations of the last two types decrease (signifies stability with respect to these perturbations), and perturbations of the first type can grow, but too slowly to lead to the formation of

galaxies or even stars. Perturbations appearing starting when density was of nuclear order were considered. Thus, a rather disheartening conclusion was obtained: gravitational instability of a uniform isotropic universe in an epoch of expansion, starting from states of nuclear density, cannot lead to the formation of cosmic bodies and systems. This result, it would seem, remains in force even if one were to consider perturbations appearing during densities exceeding nuclear, but such with which consideration of fluctuations can be made within the bounds of classical (not quantum) concepts. Thus, there remained still three possibilities: either the formation of a condensation caused not by gravitational instability, but by some other causes, or the formation of a condensation occurs at the stage of compression preceding expansion, or, finally, it is connected with perturbations on a preclassical stage of expansion. The first possibly left open the question about the origin of the condensation. The second possibility required transition to the theory of an anisotropic nonuniform universe, since transition of a uniform isotropic universe from compression to expansion through such states in which the objects being formed in outer space could be preserved is impossible. Finally the third possibility, strictly speaking, required application to the problem of formation of objects in outer space and as yet nonexistant theory, more general than the relativistic quantum theory and general theory of relativity. In recent years the idea of formation of objects in outer space as a result of gravitational instability received a new development on the basis of an investigation of Ye. M. Lifshits (see sections 31 and 33).

14. We already know that models of types A_1, M_1 and O_1 start their expansion from so-called special, or singular, states (peculiarities, singularities), i.e., such instantaneous states in which scale factor R is equal to zero, and the rate of its change $\dot{R}$, density of mass ρ and pressure p (if it is not zero) are infinite. Compression of models of these types leads them to the same singularity. These singularities limit (from one or both sides) the interval of time on which the corresponding solution (in other words, model) in general, can have physical meaning. The real value of these singularities is that at a certain, sufficiently great (but, of course, finite) density the equations of the theory lose meaning, probably, because

Einstein's theory of gravitation, as would be thought, is no longer applicable to physical conditions existing in a model with such density. The cause of the inapplicability of this theory to states of sufficiently high density its author saw in the fact that it originates from the separation of a gravitational field and all other forms of matter, which, in his opinion, is essentially incorrect and becomes impermissible at very high densities. In other words, in the opinion of Einstein, singularities indicate that at sufficiently high densities his theory of gravitation should be replaced by unified field theories. In the opinion of Lemaître and Eddington, singularities indicate that expansion starts from the state in which present ideas about time do not hold. Many physicists interpret singularity as evidence of insufficiency of Einstein's theory of gravitation at the beginning of expansion (and at the end of compression) because this theory is classical, i.e., unquantized. In light of the concepts expounded at the beginning of this piece, all enumerated points of view are equivalent.

Actually, a unified field theory usually is understood as a classical single theory of two (gravitational and electromagnetic) or three (also meson) fields. However, essentially, a unified field theory should be a single theory of all fields, which from the point of view of the relativistic quantum theory would signify together with that of a single theory of all elementary particles, inasmuch as to each type of elementary particle corresponds it equivalent field, and conversely. But fields, corresponding to particles with half-integral spin, do not have classical analogs. Consequently, a single theory of all fields and particles should be quantum and possible only on the basis of a theory more general than the general theory of relativity and the relativistic quantum theory, i.e., on the basis of a hypothetical single physical theory (possibly the last one simply will lead to a single theory of all fields and particles). After what was said it is obvious that the first and third point of view essentially are equivalent. The second point of view is equivalent to them because in just that region of physical conditions in which is necessary a single physical theory, our concepts of time.

Not having yet a single physical theory, it is impossible, of course, to say at what density it becomes necessary. It is possible only to say that this density should exceed nuclear. However, with certain parts of probability it is possible to try to give more definite appraisal. We can say that for a future theory all three baic universal constants must be essential - gravitational (γ), relativistic ($1/c$) and quantum ($\hbar$). From them it is possible to compose a single (accurate to an arbitrary numerical coefficient) constant having the dimension of the density of mass. This is the constant $c^5/\gamma^2\hbar$, equal to a magnitude of the order of 10^{94} g/cm. It is possible to think that this density should play an essential role in future theory and that the latter in any case is necessary with this density.

However, it is possible to assume that a single physical theory at the beginning of expansion is necessary not due to high density, but due to an extraordinarily fast rate of expansion. The latter is characterized by the ratio of the rate of separation of any two points to the distance between them, i.e., a quantity, having the dimensionality of t^{-1}. The value of such a dimensionality composed from three basic universal constants is $\sqrt{c^5/\hbar\gamma}$. And it is possible to think that a single physical theory in any case is necessary when the rate of expansion attains this value. But then, as follows from cosmological theory, density should be $3c^5/8\pi\gamma^2\hbar$, i.e., of the order of 10^{93} g/cm. Thus, the second appraisal practically coincides with the first. Thus, it is not excluded that Einstein's theory of gravitation is applicable to densities of the order of 10^{93} or 10^{94} g/cm.

15. Difficulties in explaining the formation of objects in outer space by the condensation of diffuse matter caused interest toward the idea of their formation from more dense - and even superdense - matter. It is not difficult to see the relationship of this idea with the hypothesis of superdense states of the metagalaxy on the early stage of its expansion. Such an idea was advanced in 1947 by V. A. Ambartsumyan in connection with this discovery of stellar associations. According to this idea stars will be formed by groups together with diffuse matter from superdense prestellar bodies (D-bodies) and then part, which the process of

star formation continues to this day. In recent years the idea of V. A. Ambartsumyan obtained further development (see below, section 31).

In that same 1947 D. D. Ivanenko and the author was expressed an idea according to which the densest objects in outer space can be the remainders of the superdense state of the metagalaxy. Thus, dense objects, according to this idea, must constitute not the final, but the initial stage of evolution.

D. D. Ivanenko and A. A. Sokolov, examining quantization of a weak gravitational field, came to the concl   n that intertransformation of gravitons and other (usual) elementary particles is possible. It was assumed that such processes are possible also in the case of a strong gravitational field, in particular in superdense states of the metagalaxy at the beginning of its expansion, and that in these states such processes can play an essential role (1947). Obviously these ideas are in agreement with the idea of Einstein shown in section 14, and go beyond existing physical theories. It was found that processes of transformation of some particles (more exactly, particles and antiparticles) into a pair of gravitons in general are much less probable than transformation of the same particles into a pair of photons or a neutrino and an antineutrino (see also Ya. B. Zel'dovich, 1963). But at superhigh density this position can change.

16. We have already talked about the material postulate of relativity of inertia (see section 2), conditioning the actual name of the theory of gravitation of Einstein as a general theory of relativity, and about the fact that Einstein's gravitational equations do not satisfy this postulate (see section 4). Nonetheless, Einstein's theory of gravitation kept the name – and understanding – as a general theory of relativity connected with the principle of general convariantness. We talked also about the fact that V. A. Fok came forward against the understanding – and name – of this theory. Discussion concerning its understanding and name was renewed with great force in 1947 and, essentially, continues at present. Let us try to see the essence of the argument and the meaning of different points of view on this question

Relativity of some quantity, or phenomenon, or fact directly signifies the dependence of this quantity, phenomenon or fact on a reference system. Absoluteness signifies the absence of such a dependence. Therefore in Newtonian mechanics the simultaneity of events of the interval of time between them, and also the geometric properties of space are absolute, whereas the distance between places of events, and also the position in space, speed and acceleration of motion, kinetic energy of any object are relative. However, according to basic concepts of Newtonian mechanics, there exists, and at the same time a unique, absolute, in other words physically preferential, system of reference, and the distance between places of events, position, speed, acceleration, kinetic energy with respect to this system of reference have an absolute character. In this meaning not only time, but also space, and kinematic values in Newtonian mechanics have an absolute character.

However, from the laws of Newtonian mechanics it follows that there exists an infinite number of inertial systems of reference (i.e., such in which the principle of inertia is valid) and that in all inertial systems of reference mechanical processes during identical initial conditions proceed equally - just as in an absolute system. Thus, there exists an infinite number of mechanically equally justified systems of reference in which laws of mechanics have an identical form and which are identical (not distinguishable) in mechanical properties. The following is essential. First, all these mechanically equally justified systems move relative to each other without acceleration; therefore, mechanical processes permit finding the absoluteacceleration of any object, but not its absolute velocity. Secondly, equations of mechanics (in general, of physics) can be written in general-covariant form, in which they have an identical form in all, and not only in inertial systems of reference; thus, the essence of mechanical equal justifications of inertial systems consists exactly in the identity (indiscernibleness) of their mechanical properties. Thirdly, from the point of view of basic concepts in Newtonian mechanics the equal justification of inertial systems does not extend to other physical (nonmechanical) phenomenon and, consequently, does not constitute full physical equal justification.

In a special theory of relativity all inertial systems physically (and not only mechanically) are equally justified. And in this theory a general-covariant (identical for all systems of reference in general) recording of basic laws of physics is possible, and the essence of physical equal justification of all inertial systems consists in the identity (indiscernibleness) of their physical properties. In Newtonian mechanics all inertial systems move relative to each other without acceleration; therefore acceleration carries an absolute character. But absolute distance between places of two events, absolute position, absolute velocity and absolute kinetic energy do not exist. Absolute simultaneity of events or an absolute interval of time between them do not exist. The absolute character of acceleration is determined by the circumstance that a universal line is accelerated by a moving particle – a curve, whereas the universal line of a particle moving without acceleration is a straight line. The distinction between a straight line and curves, and also the distinction between parallel and nonparallel lines determines the physically preferential character of inertial systems: the time bases of each of them constitute a family of parallel lines. Geometric properties of space are identical in all inertial systems of reference, but in general they are different in noninertial systems.

In Einstein's theory of gravitation, usually called the general theory of relativity, inertial systems of reference do not exist, but different generalizations in various cases are possible. The latter includes harmonic systems of reference mentioned in section 11 (for certain distributions of masses). In general there does not exist universally useful, physically preferential systems of reference. Therefore a general-covariant recording of physical laws is not simply possible, but is essential. In this is the essence of the principle of general covariantness. Consequently, all systems of reference and even all systems of coordinates are equally useful for the formulation of laws of nature, where this identity carries a fundamental character. But all these systems of reference are by no means identical in physical properties. Moreover, in different special cases there exist physically preferential systems of reference, different in various cases. In some cases a multitude of physically preferential

systems of reference exist. Such, for example, are harmonic systems in the case described in section 11. In other cases there exists a single physically preferential system of reference. Such, for example, is the accompanying system in any of the uniform isotropic models. However, in any case the presence of some physically preferential systems does not exclude the simultaneous existence of physically preferential systems of other type. Regarding, however, the absoluteness of acceleration, it occurs independently of the existence of some physically preferential systems, inasmuch as there exists a distinction between geodesic (the most direct) and nongeodesic universal lines.

Let us set certain results. In both a special and a general theory of relativity a general-covariant recording of the laws of physics, with respect to which all systems of reference are equally justified is possible. But in a special theory such a recording is not obligatory, inasmuch as there always exists a class of physically preferential systems (inertial), in which a simpler recording is possible, identical for all these systems. In a general theory the general-covariant recording is obligatory, inasmuch as there does not exist single (general) physically preferential systems for all cases. Therefore in a special theory inertial (i.e., physically preferential), and in a general theory – arbitrary (general) systems are used. But inertial systems of a special theory are identical in physical properties, and arbitrary systems of a general theory of relativity are different in properties.

In a special theory of relativity by relativity is understood identity of physical properties of the utilized systems of reference. This special theory is so-called because these systems are not arbitrary (not any). If in Einstein's theory of gravitation by relativity is understood also identity of physical properties of the utilized systems, then it will be necessary to recognize that in this theory there is no relativity. If, however, by relativity in this theory is understood the importance of application of any systems independently of a distinction of their physical properties, then this theory indeed is a general theory of relativity, but by relativity we

understand nothing of the kind that we understand in a special theory. V. A. Fok, proceeding from the requirement of identical understanding of relativity in both theories, rejects the name — and understanding — of the theory of gravitation of Einstein as a general theory of relativity. Supporters of another point of view, understanding by general relativity the principle of general covariantness, consider as correct the name and the understanding of Einstein's theory of gravitation as a general theory of relativity, changing, thus, the understanding of relativity upon transition from special theory to general.

We have already said that if one were to originate from an identical understanding of relativity in both theories, then in a general theory there is no relativity. This is true for the general case. In particular cases, exactly when there exists a multitude of physically preferential systems of reference, there is relativity, calling to mind that which is characteristic for a special theory of relativity. However, even in these cases relativity carries a weaker character than in a special theory, inasmuch as physically preferential systems nevertheless differ from each other in their physical properties.

In 1947 discussion on general relativity was connected also with the equal justification of the systems of Ptolemy and Copernicus. Inequality of these systems can be connected with the existence of physically preferential systems of reference. V. A. Fok [Fock] connected this inequality with the existence of harmonic systems.

17. At the end of the 1940's interest toward thermodynamics and statistical physics of the universe reawakened. K. P. Stanyukovich (1949-1957) examined the entropy of the universe from the point of view of statistical physics in connection with the theory of the hierarchy structure of the universe. Along with structures representing an infinite sequence of structures of progressively less scale were examined. According to conclusions of Stanyukovich, in the case of hierarchy structures of any of these two types ("broad" hierarchy and "deep" hierarchy) the entropy in any finite region of the universe grows, but for the universe as a whole, the condition of statistical equilibrium is unattainable, so that the growth of entropy goes on perpetually. Here the law of growth of entropy has meaning in relation to bounded domains, and not in relation to the universe as a whole. Unattainability of the state of equilibrium is connected with the infinity (denumerable set) of the number of stages of the hierarchy structure (see conclusions of Sheleti, section 9).

Plotkin reached other conclusions (1950-1957). According to these conclusions, in relation to the universe containing a denumerable set of particles — independent of its structure — the law of growth of entropy loses force and even the very idea of entropy loses meaning.

Distinction between conclusions of Stanyukovich and Plotkin caused discussion among these authors.

It is necessary to note that conclusions according to which for a system (universe) consisting of a denumerable set of particles, the idea of entropy inevitably loses meaning, are not quite exact. We can say only that the probability of every macroscopic state of a system is expressed by uncertainty of the form ∞/∞, and entropy by uncertainty of the form $\infty - \infty$. Uncertainty can be shown if one were to select the path of transition to the limit, but the result depends on the selection of this path. Thus, we obtain a kind of statistical or entropy paradox, externally analogous to the gravitational Zeeliger paradox.

As Zel'dovich indicated, it is possible to use the idea of specific entropy (entropy on one baryon), which has meaning when entropy is infinite.

F. A. Tsitsin (1959) noted that in an infinite hierarchy structure consecutive local minima of entropy are attained because of the interaction of subsystems of an ever higher order and on the average gigantic fluctuations in the Boltzmann conception turn out to be infinitely more rare than the corresponding scale. Furthermore, he expressed the affirmation according to which in the existence of fluctuations in case of anisotropy of space (type occurring in essentially nonlinear statistical and dynamic system with an electrical, mechanical, etc. "value") a second beginning turns out to be unjust and should be replaced by the more general position, allowing an uncompensatable decrease of entropy.

Ya. P. Terletskiy (1952-1957) backed the idea of applicability of statistical mechanics to the universe as a whole, protecting the Boltzmann fluctuation hypothesis and against the conclusion according to which the a posteriori probability of the observed picture of the world from the point of view of this hypothesis is extraordinarily small (see section 6). The essence of the objection of Ya. P. Terletskiy against this conclusion is that conditions making possible the appearance and development of living beings are examined as the result of development of the stars and planetary systems, formation and development of the stars in turn is examined as part of the process of development of the stellar system; formation and development of the stellar system — galaxy — is examined as part of the process of development of a system of galaxies — metagalaxy. According to this idea conditions which make possible the appearance and development (and not simply existence) of life must be examined as the result of a definite process of evolution of a huge region of the universe. And in such a case the a posteriori probability of the observed picture of the world (in the presence of living organisms observing this picture) can be very high and even close to unity.

As is known, statistical Boltzmann mechanics do not consider gravitational interaction of masses. Ya. P. Terletskiy arrived at conclusions by which consideration of gravitational interaction increases the probability of fluctuations. These conclusions caused an objection from M. I. Shakhparonov (1954) and discussion between the two authors.

Later (1966) I. L. Genkin attempted to apply these conclusions, generalized in the case of expanded systems, to the formation of galaxies and their clusters in the expanded metagalaxy.

Obviously, the fluctuation Boltzmann principle assumes that the universe as a whole is in a state of statistical equilibrium. In the Newtonian theory of gravitation distributions which can be considered as models of the universe in this state are known. As Sheleti indicated in 1922, the isothermal Emden spheres are the same thing (see also section 9). All these distributions possess zero average (all over infinite space) density of mass and spherical symmetry. Because such distributions possess a center, they never were examined seriously as models of the real universe. Thus, the fluctuation hypothesis in its initial form (i.e., in application to the universe as a whole) suffers a serious fundamental defect. Ya. P. Terletskiy offered a new variant of this hypothesis, in which it is applied not to the universe as a whole, but to very large regions. In this variant that part of the universe which we can observe is examined as a gigantic fluctuation inside an incomparably larger region, which is in a state close to equilibrium.

18. The prevailing form of the relativistic theory of a nonstationary universe is still the theory of a uniform isotropic universe, founded on the works of A. A. Fridman. At the same time A. A. Fridman himself was a supporter speaking the contemporary language of the relativistic theory of an anisotropic nonuniform universe (see section 3). Abroad the general problem of construction of a theory of an anisotropic nonuniform universe was posed by the American physicist Tolman (1934), the English astronomer W. McCrea

(1939) and the German astronomer Heckmann (1942). At present in favor of the development of this theory there are at least three arguments.

First, from the point of view of the theory of a uniform universe the properties and behavior of matter, including such quantitative characteristics as density of matter and rate of expansion, must be in every epoch identical in all sufficiently large regions. Consequently, they must be in all these regions the same as in the region enveloped by observations. Thus, the assumption of homogeneity makes inevitable the extrapolation of data from observations concerning the region enveloped by observations to the whole universe. But such unlimited extrapolation can in no way be justified. Consequently, the assumption of homogeneity cannot be justified. It obviously constitutes an extraordinarily severe limitation of properties of the universe. Limitation of the properties of the universe is still harder when the assumption of homogeneity is supplemented by the assumption of isotropy.

Secondly, remaining within the bounds of the theroy of a uniform isotropic universe, it is impossible to set in what measure it is possible to use its conclusions in application to other regions of the universe or to other epochs, if even in the contemporary epoch and in a known region assumptions of homogeneity and isotropy were justified with an extraordinarily high degree of accuracy. In particular, it is impossible to set how inevitable are those conclusions which are used against the theory of a uniform isotropic universe founded on Einstein's theory of gravitation in favor of other theories of a uniform isotropic universe.

Thirdly, homogeneity and isotropy on a large scale turn out to be by far not so sharply expressed and not so indisputable as it was possible to think several decades ago. In the present time it is known that there exist not only isolated galaxies, but also multiple systems, groups of galaxies, clusters of galaxies and supergalaxies.

Neither the distribution of galaxies nor the distribution of their systems to clusters of galaxies inclusively are uniform, and preservation of the assumption of homogeneity can be connected only with hopes that the distribution of supergalaxies in space will be uniform. The red shift, at least in the scales of our supergalaxy, is not strictly isotropic, and preservation of the assumption of isotropy can be connected with the hope that it will be valid in scales of greater volumes. Thus, the assumption of homogeneity and isotropy are rather badly justified in those scales for which at present there are any sufficient actual data.

At present in the theory of an anisotropic nonuniform universe it is possible to separate two main directions. One of them is a peculiar construction of simplified (but more general than uniform isotropic) models and finding the corresponding exact solutions of equations of gravitation. The first work of foreign authors in this area were dedicated to spherically symmetric models (starting from the work of D. McVittie, 1939 and R. Tolman, 1934). Models with axial symmetry and rotation are the subject of work by K. Goedel (1949 and later) and others. For the other area characteristic a general theoretical qualitative investigation of behavior and properties of an anisotropic nonuniform universe at first in any element, then in a bounded domain considering application to a region of the metagalaxy, accessible to contemporary observations, not requiring consideration of the universe as a whole finally, in application to the universe as a whole. The first work of foreign authors in this direction apparently was the work of W. H. McCrea (1939). It discusses observed peculiarities of an anisotropic nonuniform universe.

The first Soviet works on these two areas belong respectively to P. K. Kobushkin (1940) and this author (1944). Assuming axially symmetric distribution, and also the motion of matter in space, P. K. Kobushkin obtained a series of exact particular solutions to equations of gravitation and certain corollaries, in particular in reference to interpretation of the metagalactic red shift. Thus, this study directly concerns relativistic cosmology. Obviously, it was completed before the work of Goedel. Assuming the existence

of a field of speeds of matter the author of this piece examined equations of gravitation in a form describing the behavior of an element of an anisotropic nonuniform universe as an element of the accompanying space, and obtained certain results, in particular pertaining to conditions of realizing "oscillations of the second kind," i.e., oscillations of scale factor between regular extrema (regular minima and maxima). Matter was examined as dust. Development of the necessary mathematical apparatus connected with application of accompanying coordinates in general was required. The work of both authors was continued and developed by their followers.

Obviously, for the theory of an anisotropic nonuniform universe comparison of conclusions with data from observations is important, or the equivalent, finding traces of anisotropy and heterogeneity in a large scale and interpretation from the point of view of this theory. Weak anisotropy of the red shift indeed is observed, although by far not all authors acknowledge the reality of this anisotropy. Anisotropy of the red shift, if one recognizes its reality can be interpreted as a result of anisotropy and heterogeneity of expansion of the metagalaxy or part of it: visible anisotropy can be the result of both real anisotropy or real heterogeneity. Anisotropy of expansion cannot be connected with rotation, but can be the result of differential rotation. The first work on interpretation of observed anisotropy of the red shift assumed that it – completely or partly – is the result of anisotropy of expansion induced by rotation of the metagalaxy. Such was the work of the American astronomer Vera Rubin (1951), who obtained from analysis of the red shifts of 70 objects a direction to the center of the metagalaxy and the speed in it of our galaxy. Such also was the work of the Soviet astronomer K. F. Ogorodnikov, who used the red shift of 189 objects. Using the kinematics of centroids in analysis of these red shifts, K. F. Ogorodnikov determined the deviation of kinematics of the metagalaxy from isotropic expansion and interpreted part of these deviations as the result of its rotation around a center, lying in the direction of the cluster in the constellations of Virgo and Coma Berenices. For the period of inversion of our galaxy (more precisely, our local group of galaxies) around the center of the

metagalaxy a value of the order of hundreds of billions of years was obtained. Later anisotropy of expansion was interpreted as a manifestation of the rotation of our supergalaxy (hypergalaxy, local supersystem of galaxies).

19. Examining an anisotropic nonuniform universe, this author (1956-1960) kept the assumption that the substance filling the universe can be examined as a continuous medium possessing a continuous field of speeds. In this case it is possible to introduce a system of reference accompanying the substance. Basic equations of theory have been written for such a system of reference. The corresponding mathematical apparatus has been developed (use of idea of a nonholonomic space consisting of local spaces orthogonal to the time bases of the system of reference; chronometric invariants, i.e., quantity and operators, invariant with respect to conversion of time coordinate; half reverse method, allowing clarification of existence of solutions to Einstein equations, satisfying certain previously set requirements).

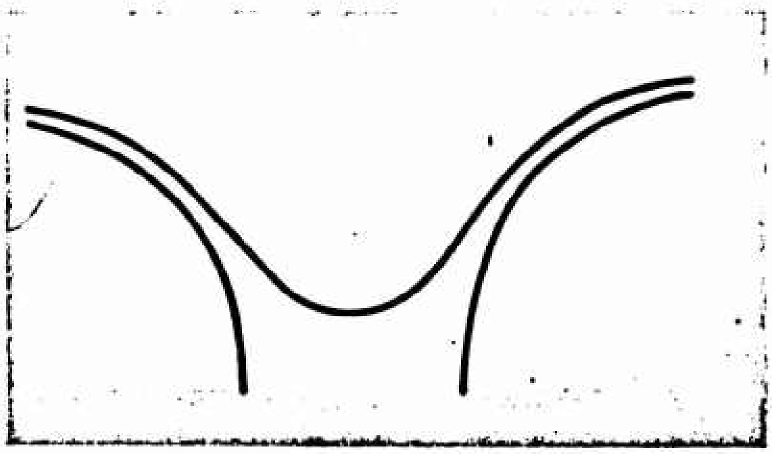
Behavior of a volume element of accompanying space with time is described by a generalized scale factor proportional to the cube root of the volume element and determined accurate to an arbitrary function of spatial coordinates. Anisotropy and heterogeneity in behavior and properties of matter and accompanying space are described in equations by six factors of anisotropy and six factors of heterogeneity. They are: anisotropy of curvature of the accompanying space, anisotropy of rates of its deformation, absolute rotation, field of force, viscous tensions, energy flow; heterogeneity of rates of deformation, absolute rotation, field of force viscous tensions, energy flow, pressure. Equations of theory set the connections among these factors, their behavior with time and their influence on behavior of the scale factor. It was clarified that when all physically necessary assumptions about the properties of matter are fulfilled (positivity of density and pressure, change of both quantities into the same side, fulfillment of the second start of thermodynamics) in a certain space-time region solutions to the Einstein equations exist, corresponding to any previously given

behavior of a volume and scale factor of the accompanying space. As a result, its expansion into one region allows possibility of simultaneous compression into another region. This conclusion makes optical treatment of the observable expansion as the expansion of the whole universe, although nonstationarity should be omnipresent.

The presence of rotation or a field of force of definite type increases the duration of the part of the epoch of expansion, which removes well-known discrepancies between this duration, enumerable in the theory of a uniform isotropic universe considering a nonpositive cosmologic constant and contemporary appraisals of ages of the oldest stars. Such solutions, by which accelerated expansion is exchanged for slow, permitting combining the lengthening of the flowing part of expansion with data from observations, according to which the megagalaxy in this epoch is expanding slowly, are possible. Within the bounds of the theory of a uniform isotropic universe such a combination, as is known, is impossible: in this theory lengthening of the flowing part of expansion is possible only with a positive cosmologic constant if expansion became accelerated while accelerated expansion cannot be changed to delayed.

Presence of the above two factors of anisotropy (rotation, field of force) makes possible such solutions of Einstein's equations according to which expansion shifts to compression, where the scale factor passes through a regular minimum, corresponding to a finite and not necessarily a very high density, instead of singularity (see the figure on p. 473). Thus, the idea that expansion of the metagalaxy began from states of superhigh density ceases to be inevitable, and the beginning of expansion took the character of an explosion. Weakness of anisotropy in this epoch becomes explainable by its decrease with expansion of the metagalaxy.

For a red shift in an anisotropic universe approximate (in linear approximation) formulas were derived, used then by Yu. P. Pskovskiy for interpretating data from observations.



Yu. P. Pskovskiy (1960) conducted a preliminary analysis of the red shifts of 310 extragalactic nebulae and determined the anisotropy of deformation (expansion) of the metagalaxy. This anisotropy, in agreement with J. de Vaucouleurs, was interpreted as a manifestation of rotation of a local supersystem of galaxies (hypergalaxies). Continuing his investigations, Yu. P. Pskovskiy (1962) examined the character of motions in the hypergalaxy by the red shifts of 370 galaxies. On the basis of obtained results he concluded that the hypergalaxy does not have a single axis of rotation and the galaxy turn around a central condensation (in the Virgo cluster) with respect to a chaotically oriented orbits.

20. The possibility of coordination of data from observations with requirements of the theory of a uniform isotropic universe is connected with the measurement of very fine effects and with conclusions of stellar and galactic cosmogony. The mentioned fine effects are first a deviation of the dependence of red shift and distance on a simple proportionality, i.e., in a deviation of this dependence from linear. Secondly, such effects consist in deviation of the coefficients of this dependence on constants, i.e., their dependence on direction. The mentioned conclusions of stellar cosmogony consist in appraisals of the ages of stars, conclusions of galactic cosmogony — appraisals of the rate of change (fall) of the luminosity of galaxies with time. If one were to consider, as is accepted, that a fall of the luminosity of galaxies occurs slower than expansion of the metagalaxy and that observation data on dependence of the red shift on distance are sufficiently reliable, then the conclusion can be made that the metagalaxy expands slowly

and, moreover, that deceleration of expansion is very strong. In order to explain so strong a retardation, the gravitational action of the metagalactic matter whose presence is indisputable is insufficient. It is necessary to allow that either a large part of metagalactic matter escapes our observations and constitutes ionized gas or a neutrino, or the cosmologic constant is negative. In any case strong retardation allows the duration of the part of the epoch of expansion which is occurring to be less than $^2/_3 H_0^{-1}$, where H_0^{-1} is the contemporary value of reciprocal of Hubble's parameter, equal approximately to 10 billion years. If retardation was weaker, it would have been possible to increase the appraisal of the duration of the occurring part of expansion by a factor of one and a half, i.e., almost to 10 billion years. If the metagalaxy expanded acceleratedly, i.e., if the cosmologic constant was positive, the mentioned appraisal could easily be increased a few times, but the assumption of accelerated expansion contradicts observation data. Appraisals of ages of the oldest stars reach 25 billion years. Thus, there is apparently a contradiction between data of extragalactic observations on one hand and conclusions of cosmogony on the other. Of course, this contradiction appears only within the bounds of the theory of a uniform isotropic universe, founded on Einstein's theory of gravitation. In order to remove the contradiction within the bounds of this theory, it is usually allowed that either measurements of deviations of the dependence of red shift on the distance from linear are unreliable and the magnitude of the retardation is oversized, or the appraisals of ages of stars are unreliable and are oversized, or something else.

Apparently at present it is absolutely impossible to warrant the reality of this contradiction. Nevertheless it is used as an argument against the general theory of relativity as a basis of cosmology. Therefore it is important to emphasize that if the reality of contradiction is confirmed, it can be the only argument against assumptions of homogeneity and isotropy, but by no means against the general theory of relativity.

D. Ya. Martynov (1959) conducted an analysis of reliability and accuracy probability of determinations of radial velocities, diameters and brightness of the galaxies. He concluded that a series of effects leading to distortions in determination of integral values, in other words brightness of galaxies, makes unreliable the clarification of the fine details of dependence of red shift on distance and the theoretical conclusions founded on them, in particular determination of acceleration (braking) of the metagalaxy. It is necessary to note that definitization of observation data showed the justice of this criticism and at the same time confirmed the retardation of galactic expansion.

A number of Americans (Humason, Mayall, Sandage, 1956; Baum, 1957) concluded that data about retardation of expansion favor the type O_1 model for K = +1 (cosmologic constant of zero). In contrast Ya. A. Smorodinskiy (1959), considering the cosmologic constant equal to zero, concluded that observation data can be coordinated with the model for which duration of that part of the epoch of expansion which is occurring is close to H_0^{-1} (model type M_1 at k = -1).

A. V. Zasov (1963) attempted a more precise determination of dependence of the red shift on distance. He examined 25 clusters of galaxies and a large number of galaxies of field. The Hubble parameter was found to be 175 ± 10 km/s per megaparsec which corresponds (for its reciprocal H_0^{-1}) to 5.7 billion years and $^2/_3\,H_0^{-1} = 3{,}8$ billion years. Retardation was very stron.

It is known that discovery of metagalactic objects of new types, possessing extraordinarily high luminosity and being a great distance from us, opened a new possibility for measurement of the red shift. Red shift in spectra of these objects is so considerable that, on one hand, it transfers lines from the more short-wave part of the spectrum into the optical section, and on the other, transferring the lines into long-wave parts of the spectrum, it eliminates the optical part of visible lines. On the basis of identification of emission and absorption bands which due to the red shift move into

the optical part of the spectrum of one radiation source, I. S. Shklovskiy (1963) found $\Delta\lambda/\lambda = 0{,}848$. On the basis of absence of lines in the optical spectrum of another radiation source Shklovskiy found suppositionally $\Delta\lambda/\lambda > 1{,}25$. For both objects appraisals of distances of the order of several thousand megaparsecs were given.

21. One of the most important results in all the existence of Einstein's theory of gravitation belongs to A. Z. Petrov: in 1954 he classified fields of gravitation by algebraic properties of the Riemann-Christoffel tensor (full curvature tensor). This classification considers three basic types of space-time and certain degenerate cases. Investigation of the properties of fields of different types led to a series of essential results. Some of them have a direct relation to cosmology. First, the conclusion that each of three types includes its own form (or forms) of an empty world. Four-dimensional spaces (i.e., spaces-times) of constant curvature, already known by the name of the de Sitter, de Sitter-Einstein and de Sitter-Fridman models, constitute an empty world in the first (classification of Petrov) type. Thus, besides these empty models, allowing a reference system possessing the properties of spatial homogeneity and space isotropy ("uniform isotropic empty models"), there exist others not allowing such systems of reference. Such, in particular, are empty worlds, in the second and third types. Petrov offered also (1961) a principle of invariantly group formulation of boundary conditions on infinity, giving for every type of space-time its form of boundary conditions.

From the point of view of the usual physical ideas of an absolutely empty world, i.e., a world in which nowhere are there masses, it must possess a curvature identical in all two-dimensional directions in all points, in other words, be a world of constant curvature, inasmuch as there are no masses in it which could disturb the (four-dimensional) anisotropy and (four-dimensional) homogeneity of space-time. Therefore the conclusion that Einstein's theory of gravitation allows other empty worlds is at first glance paradoxical. A solution to the paradox can be that empty worlds of

variable curvature are not absolutely empty, but contain gravity waves possessing energy, consequently, mass. And indeed there exist certain bases to examine a field of such worlds as a wave or containing waves. However, question about the true criterion of the presence of gravity waves, is still not solved: various authors have offered a series of such criteria. Theoretical consideration of gravity waves are the subject of work by A. Z. Petrov, A. S. Kompaneyets, M. F. Shirokov and L. I. Bud'ko, B. T. Vavilov, V. D. Zakharov, E. Ya. Moldybayevaya and others. However, apparently any empty world of inconstant curvature can be examined as the maximum case of a world containing a certain distribution of masses, considering their unlimited distance in infinity. From this point of view equations of gravitation should inevitably allow empty worlds of inconstant curvature.

22. The possibility of transition of accompanying space from compression to expansion through a regular minimum of scale factor directly without singularity still does not signify the possibility of eternal oscillation of the "second kind" (O_2), i.e., between regular extrema of the scale factor (and in conformity with density), at least considering fulfillment of requirements that solutions be analytic. The question of the possibility of type O_2 can be solved by consideration of analytic continuation of solutions giving a regular minimum of scale factor. The same can be said in general about the existence of analytic solutions without singularity.

In cases examined below a general solution of Einstein's equations depends on twelve mathematically arbitrary functions of three variables (not counting a certain number of arbitrary functions from a smaller number of variables). However, since four arbitrary functions from the twelve signify only arbitrariness compose accordingly eight and four arbitrary functions. Everything said is valid in general, including the first Petrov type. In the case of second and third types the number of "physically arbitrary" functions of three variables is less than shown.

In cosmology by peculiarity or singularity (more exactly, singularity in time) is usually understood such a state with which in accompanying space the scale factor turns into zero, and its time derivative, density and pressure (if not equal to zero) into infinity. A somewhat different understanding of singularity and another postulation of the question about their presence in solutions of Einstein's equations are contained in works of Ye. M. Khalatnikov, who proceeded from certain ideas of L. D. Landau.

These authors reject application of accompanying systems of reference and use, by their terminology, synchronous (by other terminology — semigeodesic) coordinate systems, i.e., very simple systems of coordinates, possible in any system of reference freely incident in a gravitational field (in all points) and without rotation. (In uniform isotropic models the number of such systems of reference includes the accompanying, but in an anisotropic nonuniform universe this generally does not occur). From Einstein's equations it appears that the scale factor of a synchronous system after a finite interval of time (in the past or future) should turn into zero. That the scale factor turns into zero directly signifies coordinate singularity. If, however, density referred to the accompanying system or so-called square of the Riemann-Christoffel tensor turns into infinity, then, according to these authors, true or physical singularity occurs (coordinate singularity in the absence of physical is called also fictitious).

Ye. M. Lifshits and I. M. Khalatnikov (1960) examined different solutions of Einstein's equations, possessing true peculiarities (singularities) in time. Some of these solutions describe an empty world. (Let us note that not all these empty worlds belong to the first type). All the found solutions with true peculiarities turned out to be depending on a smaller number of physically arbitrary functions than maximum: in the case of an empty world this maximum number is four; in the case of a nonempty world it is eight physically arbitrary functions (everywhere we consider functions of three variables).

Further, Ye. M. Lifshits, V. V. Sudakov and I. M. Khalatnikov (1961) examined families of geodesic lines, which, first, serve as time lines of a synchronous system of coordinates and, secondly, cross into a certain supersurface, serving thus to envelope this family (caustic supersurface). A solution to Einstein's equations is examined in environments of this caustic supersurface in the form of a system of series in powers of the parameter which turns into zero on this supersurface. On the latter obviously, the scale factor also turns into zero, and consequently, coordinate singularity exists, not occurring simultaneously in various points of space (if the parameter through which the solution depends on time is itself a function of not only time, but also spatial coordinates). Substituting these series into Einstein's equations, the connection between coefficients of the series can be found. Thus it is possible to clarify: first, on what number physically arbitrary functions depends the given solution and, secondly, whether singularity localized on a caustic supersurface is fictitious (i.e., only coordinate) or true (physical).

For the case of an empty world the solution consists of six series; for the case of a nonempty world it is ten series (in the first case the unknowns are only six components of a four-dimensional metric tensor; in the second there are three more components of the four-dimensional velocity vector of matter and its density in its own or the accompanying system; four of the ten components of the metric tensor are given by conditions of synchronism of the system). According to conclusions of these authors, solutions for an empty world and for a world filled by a medium with nonvanishing pressure (nondust matter), depend on the maximum number (i.e., four and eight) of physically arbitrary functions, where singularity localized on the caustic supersurface is fictitious. Thus, it is possible to say that in the examined cases, first, expansions for solutions depending on the maximum number of physically arbitrary functions are obtained, and, secondly, true singularity of a not caustic supersurface of this type (i.e., for a selected character of expansions) is absent. Let us note that by itself this result apparently does not exclude the possibility that at a maximum number of physically arbitrary

functions true singularity is localized on a supersurface of different type (i.e., corresponding to another character of expansions).

However, if one were to assume that (see above) all solutions possessing true singularities in time depend on a smaller than maximum number of physically arbitrary functions, then the following conclusions are inevitable. First, a solution depending on the maximum number of physically arbitrary functions ("general" solution) does not contain true singularity. Secondly, all solutions with true singularities, although they depend on a smaller number of physically arbitrary functions, are not contained in the "general" solution and must be examined as special cases. Such conclusions were reached by Ye. M. Lifshits, V. V. Sudakov and I. M. Khalatnikov. As the authors stress, these results by no means prevent the beginning of expansion of the universe from being true singularity. But, inasmuch as a solution describing such behavior depends on a smaller than maximum number of functions, it should be unstable and a class of fluctuations should exist which change behavior of the universe so that it never will come to singularity, and if in future expansion it changes by compression, the latter will lead the universe not to singularity, but to a regular minimum of the scale factor.

The last conclusion is contradicted by results of Penrose (1965) and S. Houcking [Translator's Note: exact spelling not found] (1966) concerning stability of certain solutions with true singularity (for spherically symmetric distributions and for open uniform isotropic cosmologic models). These results would not contradict the affirmation that for nondust matter exists a solution with true singularity depending on the maximum number (eight) of physically arbitrary functions.

Ye. M. Lifshits and I. M. Khalatnikov (1963) and I. M. Khalatnikov (1965) found new classes of solutions possessing true singularity. All of them, as found earlier, depend on a smaller than maximum number of physically arbitrary functions.

V. A. Belinskiy and I. M. Khalatnikov (1965) offered a solution for an empty world depending on the maximum number (four) of physically arbitrary functions and possessing in a synchronous system of coordinates fictitious peculiarity, which is attained in all points of space simultaneously.

The above contradiction pertains (if one were to leave aside the case of an empty world) to the case of nondust matter.

L. P. Grishcuk (1966) examined the solution for dust matter, depending on the maximum number (eight) of physically arbitrary functions and showed that it contains true singularity, localized in all points of a caustic supersurface of the type above described.

23. Milne (at first for $\Lambda = 0$, $k = 0$, then jointly with McCrea for $\Lambda = 0$, $k \neq 0$, finally, for $\Lambda \neq 0$) noted the far-reaching analogy between relativistic equations for a uniform isotropic universe on one hand, and nonrelativistic equations for uniform isotropic deformation of a uniform medium on the other. This analogy reaches full formal agreement of relativistic and nonrelativistic equations for a change of distances in the case of dust matter. But also in the case of nondust matter can be obtained such coincidence (Ya. B. Zel'dovich, 1963) at the cost of considering in Newtonian law of gravitation the relativistic influence of pressure on the gravitational field.

The analogy shown by Milne and McCrea served as the basis for affirmations by which Newtonian mechanics and the theory of gravitation allow uniform isotropic expanded models, and for the names "Newtonian expanded universe" and Newtonian theory of expanded universe." However, these affiramtions and names need reservation. Uniform infinite distributions belong to those which lead to the gravitational paradox, and for models preserving not only homogeneity, but also isotropy, it is necessary to supplement the Newtonian law of gravitation by additional requirements.

It is obvious also that this analogy in itself is not full in the sense that it, first, was examined only for the case of uniform isotropic models and, secondly, based on comparison of relativistic equations recorded in accompanying coordinates with nonrelativistic equations recorded in nonaccompanying coordinates.

The analogy becomes more full if one were to use nonrelativistic equations of the mechanics of a continuous medium in accompanying coordinates, derived by this author (1948). Application of these equations leads to a new — above local and substantial — treatment of motion of a continuous medium, called unitary. Later (1958) this author examined logical sources of the gravitational paradox in Newtonian theory of gravitation (in Einstein's theory of gravitation, as is known, this paradox is absent). Such sources were shown to be, first, the linear character of the Poisson equation considering nonlinear character of Einstein's equations and secondly, ellipticity of the Poisson equation when the system of Einstein equations is hyperbolic. The linear character of the Poisson equation, in other words, the principle of superposition is the basis for calculation of absolute and relative accelerations, leading to their uncertainty. The ellipticity of the Poisson equation reduces the problem of calculation of the field to a problem with universal boundary conditions on spatial infinity. The physical meaning of two sources of the paradox is shown: the Newtonian theory of gravitation does not consider, first dependence of the field of the gravitational system on the energy of interaction of its parts and secondly, the finiteness of the propagation velocity of interaction.

The idea of a quasi-Newtonian approach has been introduced, which uses equations of Newtonian mechanics and — as the law of gravitation — the Poisson equation (or its generalization with cosmologic constant), but without any universal boundary conditions. Instead in every case conditions corresponding to those which are used in an analogous case in relativistic theory must be formulated. The quasi-Newtonian approach is improved if in relativistic and nonrelativistic theories accompanying systems of reference are used. Using the quasi-Newtonian approach, it is possible to calculate such relativistic quantities as curvature of space.

A classification of Newtonian fields of gravitation containing five classes from zero to four was proposed. Mass and potential are infinite, starting from the first and, accordingly, second class. Absolute and relative accelerations are infinite or are indefinite, starting from the third, and accordingly, fourth class. Uniform models belong to the fourth class. Obviously the so-called Newtonian expanded universe is in reality a quasi-Newtonian universe.

The quasi-Newtonian approach and accompanying systems of reference were used by I. D. Novikov (1961) in considering a series of nonrelativistic (Zagar, 1955; Heckmann and Schuking, 1955) and relativistic (Goedel, 1949; Heckmann and Schuking, 1958) models of an anisotropic uniform universe.

To remove the gravitational paradox A. Ya. Kipper (1962) offered a unique modification of the Newtonian theory of gravitation. In the end two systems of measurements (scales) of space and time are introduced, called gravitational and atomic. The latter uses the usual coordinates and time and the usual relationships of Newtonian theory of gravitation are valid with one distinction: in the Poisson equation instead of infinite space there is density of mass. In the gravitational system relationships of Newtonian theory of gravitation also formally maintain their form but with another distinction: coordinates (by definition) and potential are expressed by integrals with the actual infinite volume of integration (such a name was obtained by generalized divergent integrals with respect to an infinite volume in which determination does not include calculation of the limit). The Poisson equation in a gravitational system keeps its own usual form.

We note the connection of the examined modification of Newtonian theory of gravitation with the assumption of average (overall infinite space) density of mass not equal to zero. This assumption is valid only in case of distributions of the fourth class (by classification of this author).

Ya. B. Zel'dovich (1964) examined within the bounds of nonrelativistic theory the behavior of a gravitational uniform ellipsoidal distribution of dust matter with linear field of speeds, including uniform, but in general not isotropic, deformation and rotation. Uniform ellipsoidal distribution differs in that the field inside it depends only on its density and form, but not on its dimensions. Therefore consideration exactly as the limit of a uniform ellipsoid of given density considering unlimited similar increase of its dimensions is selected as the correct method of transition to infinite uniform distribution. In such case relative accelerations in all directions are always negative. However a simple determination of them requires five limitations on the second derivative of potential (manifestation of gravitational paradox). It is proposed to examine only the uncertainty of relative accelerations as the gravitational paradox, inasmuch as absolute gravitational accelerations are unobserved. At negative total energy in the general presence of rotation and anisotropic deformation uniform distribution should pass through a state in which matter is compressed without limit in the direction of the axis of rotation and expands without limit in orthogonal directions, where density becomes infinite. Narlikar's work (1963) is criticized because this author, examining an anisotropic universe, considers the field of relative accelerations to be isotropic. Results of nonrelativistic and relativistic consideration were compared. Inasmuch as there are known solutions for an anisotropic uniform universe (O. Heckmann and Ye. Schuking, 1958) by which the sign of relative accelerations can be changed, which is impossible using the proposed method of nonrelativistic consideration, it was concluded that local properties of a relativistic solution of cosmologic problem cannot be found by nonrelativistic consideration.

The result at the basis of this conclusion is connected with the selected method of passage to the limit. A quasi-Newtonian approach allows a solution formally coinciding with the examined relativistic Heckmann-Schuking solution (see the cited work of I. D. Novikov).

Keres (1964) offered a method of comparison of the fields described by the Newtonian and Einstein theories of gravitation, founded on the use in both theories of systems of reference which are incident freely without rotation (but deformed). This makes it possible to describe the gravitational field in Newton's theory using a three-dimensional quadratic form (it is known that in Einstein's theory this is possible in the mentioned systems of reference).

According to Keres (1965), there are two types of solutions to Einstein's equations, Newtonian and non-Newtonian. Solutions of the first type in the nonrelativistic approach satisfy the Newtonian theory of gravitation (irrotational fields); solutions of the second type do not satisfy it (vortex fields). The latter are characterized not only by scalar Newtonian potential, satisfying Poisson's equation, but also, by vector potential, satisfying the Laplace equation. Later (1966) he showed all solutions of the Einstein equations for empty space, which in a proper system of reference satisfy also the Newtonian equations. It has also been concluded that the Petrov classification of gravitational fields has no analog in Newtonian theory.

24. In the special and general theory of relativity there exists a single (in every case) space-time metrics and accordingly a single type of length standards and a single type of time standards. In the kinematic theory of relativity and the kinematic cosmology of Milne there exist two types of length standards and accordingly two types of time standards, where every type of time standard corresponds to its own type of length standard. Thus, there exist two space-time scales (by Milne's terminology) — kinematic and space. In the kinematic scale distances between galaxies grow in proportion to time; in the space scale they are constant. But this is rare. In the kinematic scale the volume occupied by the metagalaxy is finite; in the space scale it is infinite, although the volume of all space is infinite in both scales. Further, in the kinematic scale the age of the universe (more precisely, time from the beginning of its expansion) is finite; in the space scale the age of the universe is infinite. Thus, Milne's theory contains the

idea of relativity of the finiteness and infinity of space and time, connected with the presence of two space-time scales in it. Obviously, such relativity of the finiteness and infinity of space or time cannot exist either in the special or general theory of relativity.

However, in Milne's theory the two scales are connected with two different systems of reference. In the system of reference with which the kinematic scale is connected, the galaxies move; in the system of reference with which the space scale is connected, the galaxies are at rest: this is a comoving, but not deformed (in the space scale) reference frame. Consideration of the question shows that the relativity of finiteness and infinity of the volume occupied by the metagalaxy is caused by Lorenz reduction connected with the relative motion (relative deformation) of the two systems of reference, and in the end is rooted in the relativity of simultaneity. Consequently, relativity of the finiteness and infinity of the volume occupied by any system, more precisely relativity of the space finiteness and infinity of some space-time region, is peculiar also to the special and general theory of relativity. Such a conclusion was reached by the author of this piece (1959) irrelevantly of the theory of Milne by consideration of the transformations connecting the Minkowski and Robertson reference frame in the de Sitter-Einstein model (see figure on p. 435, cases $\Lambda = 0$, $k = 0$ and $k = -1$, type SE): all infinite space of the Robertson calculation in this case occupies in the Minkowski system of reference the volume of a sphere increasing without limit, but always of finite radius. An analogous result was also obtained for the de Sitter-Fridman model (empty model with $\Lambda < 0$). Here, however, in both the case of the de Sitter-Einstein model and the de Sitter-Fridman model all space remains infinite in each of the two examined systems of reference — in both static (Minkowski), and nonstatic (Robertson).

A more paradoxical position was revealed in the case of the de Sitter model (empty model with $\Lambda > 0$). It was known that in this model the space of the Lantsosh system of reference (see figure, case $k = +1$, type S) was certainly closed, whereas space of the

Lemaître and Robertson reference systems (see figure, cases k = 0 and k = -1, type S) is infinite. (This fact was treated as a possibility of different geometric interpretation of the de Sitter model, caused by the absence of matter in it — see, for example, E. Shredinger, 1956.)

Consideration of the transformations connecting the Lantsosh system with the Lemaître and Robertson systems showed that each of the infinite spaces of the last two systems occupies in the space of the first system the volume of a sphere of finite, ever increasing radius, where the volume of space of the Lantsosh system, as is apparent from above, is finite.

Combining results obtained for different Λ, we see that the same space-time region can be space-finite in one system of reference and space-infinite in another system of reference, where the space-time world with infinite space can be part of a space-time world with finite closed space. This conclusion was reached by this author for empty models, while its validity is questioned for a world filled with matter. Later (1962) he found an example of the relativity of finiteness and infinity of space of a model filled with matter.

In these cases the relativity of finiteness and infinity touches space, but not time. However, work of Oppenheimer and Snyder (1939) contains an example of the relativity of finiteness and infinity of time. Namely, in a comoving reference frame collapse of a gravitational sphere from any state to compression into a point (formally) occupies a finite time, whereas in a stationary system, defined outside the sphere (in an external system), compression to the radius equal to the gravitational, i.e., part of the process of collapse, occupies an infinite time.

New examples of relativity of the finiteness and infinity of both space and time were given by I. D. Novikov (1961, 1962). It is known that in an external system of reference the space-time region lying inside a singular sphere (Schwartzschild sphere or sphere of

gravitational radius in the case of an electrically neutral mass and an analogous sphere in case of a Nordstromfield, i.e., gravitational field of electrical charge), space is finite (bounded), but is infinite in time. I. D. Novikov showed that in a nonstationary system of reference, realizable inside such a region, the latter, on the contrary, is space-infinite, but is finite (bounded) in time.

Let us note that if an answer to the question of finiteness or infinity of space depends on the system of reference, the value of this circumstance is strengthened when there exists no unique system of reference for the whole universe which would be physically preferential. The same pertains to time. In cosmology such a system is comoving. But in an anisotropic nonuniform universe there cannot be a comoving system which is unique for all its regions. Therefore relativity of the finiteness and infinity of space and time can play an essential role namely for an anisotropic nonuniform universe.

25. These mentioned results of I. D. Novikov are contained in his works dedicated to consideration of spherically symmetric fields and distributions of masses. In these works methods mentioned in section 19 were partially used. In particular, the work showed the possibility (under certain assumptions) of shifting from compression to expansion through a regular minimum of scale factor, simultaneous throughout space. This conclusion is obtained for such spherically symmetric distribution of masses in which density upon removal to infinity sufficiently rapidly tends to zero. Later I. D. Novikov (1964) concluded the possibility of arbitrary behavior of a volume element of a medium on an infinite interval of time.

In the general case of spherical symmetry I. D. Novikov showed the presence of regions of essential nonstationarity, in which the surface area of sphere described from the center of symmetry does not depend on its radius, but changes in time. Such regions are called T-regions in contrast to R-regions: in the latter it is possible to draw a sphere (described from the center of symmetry) whose surface area does not depend on time, but it is impossible to exclude the dependence of this area upon the radius of the sphere.

These results are applied to the metagalaxy. It was shown that radio observations permit fixing sources apparently lying in T-region both at the time of radiation and at the time of observation. In such a case, if the metagalaxy possesses spherical symmetry, its expansion had to start from singularity. The properties of metrics in regions lying inside singular spheres were examined for the case of Schwartzschild, Nordstrom and Kottler (analog of Schwartzschild field for a cosmologic constant not equal to zero). These regions (in the second and third case — considering fulfillment of certain conditions) belong to the number of regions of essential nonstationarity. I. D. Novikov (1964) considered the propagation of light and the motion of particles in regions of essential nonstationarity. As Novikov showed, inside a singular sphere outside the masses only such systems of reference are realized whose direction of deformation (i.e., expansion or compression) coincides with the direction of deformation of the main mass. It is such a direction of the pulse of signals which can be carried out through the surface of a singular sphere.

It is known that singularity on the Schwartzschild sphere is peculiar to a stationary system of reference and is absent in freely incident systems of reference. At the same time the velocity of freely incident systems relative to a stationary system on the Schwartzschild sphere is equal to fundamental velocity. In view of this there exist differences about whether singularity is removed to the Schwartzschild sphere by transition from a stationary to a freely incident system or merely obtains another form. Yu. A. Rylov (1961) favored the first answer, and V. Ount [Translator's Note: exact spelling of name not found] (1961) the second.

Affirmation that any spherically symmetric field in a vacuum is stationary (i.e., lies in an R-region) is known as Birkhoff's theorem. Naturally, this theorem is valid under certain, partially implicit assumptions. By analyzing these assumptions, A. Z. Petrov (1963) concluded that they exclude solutions of the shock wave type, and proposed a general solution to the question about a spherically symmetric field in a vacuum. Still earlier Ount (1962) had showed

that strict proof of Birkhoff's theorem is impossible without disturbing conditions imposed by A. Likhnerovich on the utilized systems of coordinates. Ount indicated also (1963) that the well-known stationarity of metrics inside a cavity in the expanded universe is incompatible with the use of coordinate systems satisfying requirements of Likhnerovich. A. P. Ryabushko (1964) offered a more precise definition of Birkhoff's theorem by which any spherically symmetric field in a vacuum satisfying Einstein's equations is equivalent to a Schwartzschild field (i.e., stationary field) or its part, if continuity of transformations of coordinates and one-to-one conformity are not required.

Ya. B. Zel'dovich and (independently) I. D. Novikov examined (1962) spherically symmetric models of a semiclosed world, including the greater part (more than half) of the nonstationary Fridman spheric world and the surrounding external space, in which it constitutes a nonstationary gravitational sphere. The greater the part of the Fridman world it contains, the less (due to the greater gravitational mass defect) its gravitational mass. Considering approach without limit to the case of a complete closed world this gravitational mass tends to zero. These models show in particular the possibility of essential weakening of the gravitational field of the sphere by addition of a spherically symmetric layer of substance due to the increase of gravitational mass defect. Questions on evolution of a semiclosed world and on the possibility of an exchange of signals between it and the external space were examined also.

I. D. Novikov and L. M. Ozernaya (1963) examined the propagation of light in a Lemaître reference frame which is freely incident in a spherically symmetric field in a vacuum, including the region lying inside a singular Schwartzschild sphere. Results were applied to numerical calculation of the form of exploding mass whose initial linear dimensions are less than its gravitational radius. In this system of reference the observer is able to obtain light emitted by the mass prior to going beyond the limits of the sphere, but this light will reach the observer only after its exit.

Later R. I. Khrapko (1965) examined different systems of coordinates which are applicable for the described semiclosed world from the point of view of fulfillment of Likhnerovich's conditions of continuity. He proposed (1966) an analytic solution to the problem of calculation of the form of a gravitational sphere expanding at parabolic from within a Schwartzschild sphere. The same author investigated the structure of a world of special type, including metrics of Schwartzschild, de Sitter, Kottler and Nordstrom as particular cases (1966).

26. On one hand, spherically symmetric distributions and motion of masses belong to those most simple and accessible for theoretical research. On the other hand, many objects in outer space are close to it in structure. Therefore it is natural that consideration of such distributions and movement was dictated both by development of Einstein's theory of gravitation, and by the need for theoretical explanation and investigation of the properties of real objects. In this connection a special role in recent years was played by the necessity of explaining the nature of powerful sources of energy (supernovae, radio galaxy, quasars and so forth) and in general, description of processes accompanying the liberation of huge amounts of energy. Interest toward gravitational phenomena is connected with the fact that in principle it is possible to explain an incomparably greater yield of energy than by nuclear reactions.

A cycle of works dedicated to problems of relativistic (within the bounds of the general theory of relativity) hydrodynamics and gas dynamics mainly for the case of spheric symmetry was carried out by V. A. Skripkin (1958-1961). V. S. Brezhnev (1966), and also V. S. Brezhnev, D. D. Ivanenko and B. N. Frolov (1967) examined solutions to the Einstein equations describing Fridman asymptotic behavior on infinity.

Spherically symmetric movement of matter within the bounds of the general theory of relativity was examined also (1965) by K. P. Stanyukovich and S. M. Kolesnikov (motion of dust matter and adiabatic motions of nondust matter), K. P. Stanyukovich,

O. Sharshekeyev and V. Ts. Gurovich (ultrarelativistic dispersion of gas).

A series of works was specially dedicated to explanation of the nature of quasars (and also the radiogalaxies) by the phenomenon of collapse or the opposite process, anti-collapse. (We mention only those explanations of the nature of quasars for which the effects of the general theory of relativity are essential.) The hypothesis of anti-collapse is the subject of a work of I. D. Novikov (see section 31). From the point of view of this hypothesis the above (see section 25) work of I. D. Novikov and L. M. Ozernaya is of interest.

However, attempts to explain large yields of energy led to rejection of strict spheric symmetry, and in time to the idea of essential nonsphericality.

It is well-known that gravitational collapse without limit by a rising red shift (Einstein and Doppler) essentially extinguishes electromagnetic radiation of a collapsing body. Criticizing Michael's idea (1963) on the role of the neutrino and neutrino radiation in the phenomenon of quasars, Ya. B. Zel'dovich (1963) indicated that gravitational collapse extinguishes neutrino radiation the same way. In connection with the impossibility of guaranteeing a sufficient yield of energy in a spherically symmetric collapse, Ya. B. Zel'dovich simultaneously noted the value of asymmetric movement of substances in the processing of gravitational energy of a collapsing star (in energy of radiation and cosmic rays) and in other processes accompanying collapse.

During observable phenomena of the release of large amounts of energy the radiation of gravity waves as a by-product is also possible. Energy release by means of gravity waves appearing due to asymmetric motions of substance was examined in connection with the phenomena of collapse by I. S. Shklovskiy and N. S. Kardashev (1964), Ya. B. Zel'dovich and I. D. Novikov (1964). Gravitational radiation due to asymmetric motions of substance considering anti-collapse (explosive phenomena) was examined by L. M. Ozernaya (1965).

(For prospects of the detection of gravitational radiation, see V. B. Braginskiy, 1965.)

The idea about gas infall in a powerful gravitational field as a source of energy of radio emission was posed by I. S. Shklovskiy (1962).

Ya. B. Zel'dovich (1964) indicated process of liberation of gravitational energy during asymmetric accretion through the gas glow in the shock wave forming upon its fall in the gravitational field of a collapsing star.

Observation of this phenomenon gives a method of detecting collapsing stars. Another method of detection in the composition of spectroscopic binaries with invisible satellites was shown by O. Kh. Guseynov and Ya. B. Zel'dovich (1966).

Ya. B. Zel'dovich and I. D. Novikov (1964), assuming that in the atmosphere of a quasar radiation pressure is balanced by gravitation, found for the mass of the quasar nucleus a value of the order of 10^8 solar masses. A disturbance of this equilibrium in the external layers leads to their ejection. As a possible mechanism of the generation of energy by a quasar they indicated the accretion of substance of the atmosphere (around three solar masses a year) in a small environment of a collapsing nucleus.

According to Einstein's theory of gravity, the gravitational field depends not only on distribution of masses, but also on their motion and state. In particular the field of a body depends on its rotation. This dependence leads to the appearance of a dynamic effect analogous to the Coriolis effect. Ya. B. Zel'dovich (1965) showed that, due to this dependence, in the field of revolving stars should exist a gravitational analog of the Zeeman effect. This dependence appears also during accretion: as A. G. Doroshkevich showed (1966) the moment of momentum of a revolving body decreased during the accretion of substance possessing no moment. The moment of collapsing stars decreases fastest of all.

V. L. Ginzburg (1964) expressed the hypothesis that quasars constitute radiation belts around large collapsing magnetic protostars. V. L. Ginzburg and L. M. Ozernaya (1964) investigated the gravitational collapse of a spherically symmetric mass of gas with zero pressure and possessing a magnetic moment. According to the obtained conclusions, the magnetic moment of the star for an outside observer fades by power law, and the growing magnetic field contracts to the Schwartzschild surface.

I. D. Novikov (1964) examined the change of magnetic moment during the collapse of magnetic stars as a possible mechanism of radiation of electromagnetic waves by quasars. N. S. Kardashev (1964) examined the intensification of magnetic field of a revolving cloud of plasma during gravitational compression as the cause of observed peculiarities of powerful sources of nonthermal radiation.

The above models essentially are nonstationary. Meanwhile quasars are quasi-stationary objects. L. M. Ozernaya (1964) proposed a magnetoid theory — a massive plasma quasi-stationary configuration, whose equilibrium is supported by regulated circulatory flow of plasma in a large-scale magnetic field, and concluded the possibility of explaining properties of quasars within the bounds of a magnetoid model.

Massive configurations stabilized by rotation during slow loss of mass through the outflow of substance from the equator was examined by G. S. Bisnovatyy-Kogan, Ya. B. Zel'dovich and I. D. Novikov (1967). But let us return to work dedicated to collapse.

27. A. G. Doroshkevich, Ya. B. Zel'dovich and I. D. Novikov (1965) examined gravitational collapse of asymmetric and revolving masses. It was shown that, as P. Bergman assumed (1964), the characteristic picture of gravitational self-closing, just for the spherical case, is preserved in the general case. Moreover, in the case of collapse of an irrotational body quadrupole and higher field moments caused by asymmetry for an outside observer change in inversely proportion to time. In the case of collapse of a rotating

body deviations in metrics connected with the rotation, while fading, do not disappear. Static nonspherical solutions of the Einstein equations are examined also and, in particular, properties of a surface analogous to the Schwartzschild surface.

Ya. B. Zel'dovich and M. A. Podurets (1965) examined the evolution of a system of heavy point particles. As effects leading to evolution, they considered: evaporation of particles and gravitational radiation and adhesion. According to conclusions of the authors, a system, slowly evolving, passes a sequence of quasi-equilibrium states, where evolution is inevitably completed by collapse. Applicability of results to astronomical objects was discussed also. This investigation presents interest in connection with the idea that quasars are collapsing galaxies.

Examining the behavior of an electrically charged dust sphere, I. D. Novikov (1966) concluded that its compression inside the Schwartzschild surface is changed by expansion, where the preceding stage of compression, occurring prior to submersion of the sphere inside this surface, and the subsequent stage of expansion, occurring after the sphere leaves this surface, occur in identical (but not coinciding and separated in time) space-time regions, Euclidean on space infinity. Maximum average density has the order $c^6 m^4/\varepsilon^6$, where m — mass, ε — charge. Infinite density is attained only in the center. The assumption was expressed that growth of perturbations or quantum effects must lead to the same behavior of an uncharged (neutral) material sphere.

M. Ye. Gertsenstein (1966) examined gravitational collapse as a stage in pulsation with passage of substance through singularity in the center, where the maximum radius of the central body exceeds the gravitational radius. Such an oscillatory process is discussed as quasar behavior. According to conclusions of this author, periodic collapse in principle is seen for an outside observer and does not exclude the radiation of great amounts of energy. Gertsenstein and Yu. M. Ayvazyan (1966) examined the picture of oscillatory collapse from the point of view of an outside observer

and concluded that in this picture the symmetry of compression and of expansion is not disturbed.

Obviously, the picture of the oscillatory process contradicts well-known results of Oppenheimer and Snyder (see section 24). These results, if one were to examine passage through singularity, would not be contradicted by the conclusion that compression of the sphere outside the Schwartzschild surface and subsequent expansion outside this surface will occur in different space-time regions, just as was clarified by I. D. Novikov for the case of an electrically charged sphere (see above).

28. Consideration of simple anisotropic relativistic models was stimulated both by the logic of development of the actual theory and by the necessity of explaining certain facts (see below).

P. K. Kobushkin continued his investigations of axisymmetric distributions and movements of matter within the bounds of the general theory of relativity. He examined the exact solution of the Einstein gravitational equations for the case of a stationary axisymmetric field and generalization of the Fridman solution for the case of a nonstationary axisymmetric field (1963). A. A. Koppel' (1963-1965) examined exact axisymmetric static solutions of the Einstein equations. The statistic axisymmetric solutions of problem of many particles in the general theory of relativity and clarification of the physical meaning of these solutions are the subject of work by I. R. Pierre [Translator's Note: exact spelling not found] (1964-1965).

A. S. Kompaneyets and A. S. Chernov (1964) obtained solutions to the Einstein equations for a nonstationary uniform axisymmetric model of the universe in two limiting cases: dust matter and ultrarelativistic gas. The solutions possess a peculiarity in a certain moment of time. A solution for nonrelativistic gas with an isentrope factor was obtained also.

In connection with problems of cosmic rays, structure of galaxies, quasars, etc., in recent years the existence of intergalactic magnetic fields has been widely discussed. Generalizing the idea of S. B. Pikel'ner, Piddington and others, Ya. B. Zel'vodikh (1965) assumed that in the universe there exists a primordial uniform magnetic field. Solutions are examined for a universe which is uniform, but anisotropic thanks to the primordial magnetic field (i.e., uniform axisymmetric universe). The magnetic field turns out to be frozen in the medium. Its suppositional value in the contemporary epoch is less than 3×10^{-9} G. A vortex electrical field created by the change of magnetic field, is absent for an observer moving together with the substance. It was noted that the magnetic model fully agrees with the assumption of cold substance

and presence of the neutrino on the early stage of evolution (see section 30).

A. G. Doroshkevich (1965) examined a series of exact solutions of gravitation equations for anisotropic uniform models of the universe with magnetic field (more exactly, uniform axisymmetric models with a magnetic field directed along the axis of symmetry) and without it. The behavior of solutions near a singularity and on late stages of expansion was investigated. It was clarified that a magnetic field can strongly affect the character of behavior of the model near a singularity (i.e., on initial stages) considering any equations of state, but on late stages of expansion the effect of the magnetic field is imperceptible. It was shown that the objection of F. Hoyle to inclusion of the magnetic field in the cosmologic solution is incorrect. (Hoyle considered that the ratio of energy of a magnetic field to total energy of substance in an approach to singularity grows without limit.)

Uniform axisymmetric models with magnetic field directed along the axis of symmetry were examined also by I. S. Shikin (1966).

A. G. Doroshkevich (1966) briefly examined gravitational instability of anisotropic uniform models of the universe. It was shown that in such models the amplification factor of initial heterogeneities is considerably greater than in uniform isotropic models. The magnetic field effect was examined also. It was shown that calculation of possible anisotropy of expansion can be important in building a theory of the formation of objects in outer space not only in a "cold," but also in a "hot" universe (see section 30).

A. G. Doroshkevich, Ya. B. Zel'dovich and I. D. Novikov (1967) indicated that in an anisotropically expanded universe weakly interacting particles (neutrino, gravitons) moving in various directions change their momentum in different ways, which in turn strongly changes the picture of anisotropic expansion. In particular, a neutrino density greater than in an isotropic universe.

I. M. Khalatnikov (1967) examined a stationary cylindrically symmetric model filled with substance having the equation of state $p = n\rho c^2$ and a magnetic field. In connection with this model the possibility of considering quasars as magnetogravitational formations was discussed.

29. As was already said, the ruling forms of the relativistic theory of a nonstationary universe to this day remains the theory of a uniform isotropic universe.

An attempt to remove singularity within the bounds of this theory was undertaken by M. F. Shirokov. Initially (1959) he proposed a model with an exponentially increasing scale factor and negative pressure. This model differs from the equilibrium model of F. Hoyle by the physical interpretation of the right sides of the Einstein equations. Later M. F. Shirokov and I. Z. Fischer (1962) proposed a derivation of equations for uniform isotropic models by averaging equations of models with weak local deviations from homogeneity. In such a way additional terms are obtained in equations (analogous to negative pressure), which could remove singularity if one were to allow that equations derived in assumption of the smallness of deviations from homogeneity remain valid when these deviations are not small. Later (1965) M. F. Shirohov attempted to improve the derivation of equations by rejecting the assumption of smallness of deviations from homogeneity.

Let us note that according to the opinion most widely spread at present, removal of singularities within the bounds of the theory of a uniform isotropic universe, founded on Einstein's theory of gravitation, i.e., prior to transition to a more general physical theory, is impossible.

Behavior of the scale factor on early stage of expansion (near singularity) essentially depends on the equation of state. If later it is presented in the form: $p = n\rho c^2$, p — pressure, ρ — density of mass, then near singularity $R \sim t^{2/3(n+1)}$. Thus, in the case of dust matter $(n = 0)$ $R \sim t^{2/3}$. But at high densities matter should behave

as ultrarelativistic gas ($n = 1/3$), so that $R \sim t^{1/2}$. However, as Ya. B. Zel'dovich showed (1961), when density is much greater than nuclear, $n = 1$ is possible (in general $n < 1$), so that $R \sim t^{1/3}$. Thus, on the earliest stage the rate of relative expansion had to be less than was assumed.

A general consideration of the superdense state of matter in a uniform isotropic universe was conducted by G. S. Saakyan (1962).

The idea that the metagalaxy constitutes a limited expanded system of galaxies was again developed (see section 8) by G. M. Idlis. Here the metagalaxy is examined as a typical system of inhabited galaxies, which signifies the groundlessness of extrapolation of the physical conditions ruling in it to the whole universe (1958). According to G. M. Idlis (1962) the metagalaxy constitutes an "autonomous" space system, which in the contemporary epoch can be approximately represented by a closed uniform isotropic model with Hubble parameter equal to 75 km $\times$ s^{-1} $\times$ Mps^{-1}, and with quantitative predominance of radiation over substance — with densities of the order of 10^{-29} and 10^{-31} g-cm^{-3} respectively. Additional forces in the metagalaxy causing the predominance of radiation were examined by G. M. Idlis, Z. Kh. Kurmakayev and T. B. Omarov (1963).

We see, thus, application of the relativistic theory of a uniform isotropic universe to a limited system as an approximation. (To limited systems it is possible to apply strictly only models filled with dust matter, since otherwise it is necessary to consider the heterogeneity of pressure.) Let us note that according to contemporary data the density of electromagnetic radiation is several orders lower than the density of substance.

For uniform isotropic cosmologic models filled with dust matter or radiation (in general, ultrarelativistic gas) exact solutions of equations of gravitation are known. However, metagalactic matter can be examined faster as a mixture of dust substance and radiation (especially if a considerable part of this

matter is composed of neutrinos). A. D. Chernin (1966) obtained exact solutions of equations of gravitation (without the cosmologic term) for uniform isotropic models filled with such a mixture, and found corresponding models of expression for the red shift, quantity of substance up to a given red shift, visible brightness and visible angular dimension of objects.

K. P. Stanyukovich (1966) examined geodesic lines in uniform isotropic models. K. P. Stanyukovich and O. Sharshekeyev (1966) converted Schwartzchild and Fridman intervals to a form in which turns out to be Euclidean metrics of space sections, not orthogonal to time bases (not space metrics).

Applying the theory of a uniform isotropic universe to the real universe, it is necessary to consider the presence of local heterogeneities in the distribution of mass, in other words, the fact that at least part of the substance is concentrated in cosmic bodies and systems. An attempt to remove singularity by calculation of local heterogeneities was mentioned above. Here we will examine other examples of such calculation.

The momentum of a particle moving in a uniform isotropic expanded universe with respect to a comoving reference frame should decrease in time. This affirmation usually is extended to the peculiar motion of galaxies in the expanded metagalaxy. In such a way Hoyle obtained affirmation. That in the past the speed of peculiar motions of galaxies had to be incongruously great, which in his opinion generally contradicted Fridman's theory. However, the law of decrease of momentum of any particle during expansion of universe loses force during calculation of local heterogeneities of density. The derivation of this affirmation, and also equations considering the influence of local heterogeneities, was proposed in a work of N. A. Dmitriyev and Ya. V. Zel'dovich (1963).

Obviously, visible angular diameters of objects of identical linear dimensions must be less the further they are from the observer. However, it is known that in relativistic cosmologic models this

affirmation is true only up to the certain distance on which apparent diameters reach minimum and after which they begin to grow. In the work of Ya. B. Zel'dovich (1964) it wa shown that conclusions concerning angular dimensions of distant objects in a uniform isotropic universe are valid only when the average density of mass in the cone of rays going from object to observer does not differ from the average density of mass in the universe. If in this cone there are no masses (which is possible when masses are concentrated in galaxies), then the angular diameter of remote objects does not pass through minimum. The work of Ya. B. Zel'dovich examined the case of zero curvature of space. Analogous conclusions were obtained for a nonzero curvature of space by V. M. Dashevskiy and Ya. B. Zel'dovich (1964).

V. M. Dashevskiy and V. I. Slysh (1965) generalized these investigations in the case in which, besides matter concentrated in galaxies, there exist also masses distributed evenly (radiation, intergalactic gas). They concluded that in this case the angular diameter vs distance curves always should have minimum.

Until now we have talked about calculation of heterogeneities in distribution of masses. A. D. Chernin (1966) examined uniform isotropic cosmologic models with chaotic magnetic field. He found exact solutions of the equations of gravitation for such models and investigated the gravitational stability of these models.

To select the model which best corresponds to behavior of the metagalaxy, it is important to use date of extragalactic astronomy, concerning the whole region enveloped by observations. In this connection quasars are of great interest, inasmuch as they, thanks to their considerably great luminosity, are seen from farther distances than galaxies. Examining the possibility of determination of average metagalactic density of substance according to observations of quasars, V. M. Dashevskiy and Ya. B. Zel'dovich (1967) analyzed deficiencies of the usual methods, founded on observation of distributions of apparent magnitude or of red shift, and proposed a new method consisting in counting the number of objects with red shift

and apparent magnitude not greater than a certain magnitude. At the same time it was stressed that conclusions depend so much on the assumed law evolution of observed objects that data from observations can be coordinated with any cosmologic model at the cost of the corresponding assumption.

30. The problem of the origin of chemical elements one way or another has been connected with relativistic cosmology, more exactly, with the relativistic theory of a uniform isotropic universe for already 40 years. Initially it was attempted to tie the origin of the elements to the initial stage of expansion of a uniform universe, in other words, its high-density states. However, it turned out to be impossible to explain the observed chemical composition of a certain part of the universe, i.e., relative abundance and even origin of different elements heavier than helium. Later it was possible to explain satisfactorily the origin of all elements heavier than helium, (and also helium itself). The understated estimate of the relative quantity of helium in the universe led to the assumption that all elements heavier than hydrogen were formed in the stars, whereas stars of the first generation were formed from hydrogen. Thus, the cosmologic theory had to provide for purely hydrogen composition of the universe in the prestellar epoch. But just this caused difficulties.

If on the initial stage of expansion temperature was very high and the mass of substance (nucleons) was very small as compared to the mass of radiation (hypothesis of the "hot" universe, proposed by G. Gamov), in the prestellar epoch the mass of substance had to be composed of 70% hydrogen and 30% helium. If, however, on the initial stage of expansion temperature was low and matter consisted of neutrons (hypothesis of the "cold" universe considered by Solpeter), then on the prestellar stage heavy atomic nuclei had to quantitatively strongly predominate over light nuclei.

Ya B. Zel'dovich (1962) offered a new variant of the hypothesis of the "cold" universe, by which on the initial stage of expansion the absolute temperature was equal to zero and matter consisted of

protons, electrons and neutrions in equal – with respect to the number of particles – quantities, where at high density all these particles were in a state of degenerated Fermi-gases. The presence of neutrinos prohibited capture of an electron by a proton, leading to the formation of a neutron and a neutrono, and thus stabilized the protons. During expansion such substance turns into hydrogen, from which will be formed the first generation of stars.
V. Ya. Yakutov (1964) examined nuclear reactions and the physical state of substance on early stages of expansion of a "cold" universe.

Ya. B. Zel'dovich, L. B. Okun' and S. B. Pikel'ner (1965) traced the fate of quarks in "hot" and "cold" models of the universe and in the stars. It was shown that in the contemporary epoch the concentration of quarks in relation to nucleons in "hot" and "cold" models should be respectively 10^{-10} to 10^{-13} and 10^{-18}. (Later, after discovery of new factors (see section 32), Ya. B. Zel'dovich came forward in favor of the hypothesis of the "hot" universe).

31. The relativistic theory of gravitational instability, proposed by Ye. M. Lifshits in 1946 (see section 13) and then augmented by Lifshits and I. M. Khalatnikov (1963), found new application to the solution of the problem of formation of cosmic objects under different physical conditions.

The English astronomer V. Bonner (1957) noted that the theory of gravitational instability of Jeans in its initial form is incorrect, inasmuch as it examines an infinite static distribution of masses which do not satisfy Newtonian theory. As Ya. B. Zel'dovich (1963) noted, this incorrectness in a certain meaning is connected with the gravitational paradox. However, Jean's general approach we will apply to nonstatic distributions satisfying nonrelativistic theory (i.e., essentially quasi-Newtonian approach). As Bonnor showed, the results of Ye. M. Lifshits in the nonrelativistic approach pass into results obtained in such a nonrelativistic theory (actually – quasi-Newtonian), of gravitational instability as a corrected Jeans theory.

A. G. Doroshkevich and Ya. B. Zel'dovich (1963) examined in the nonrelativistic approach gravitational development of perturbations of density and speed in a uniform medium experiencing uniform isotropic expansion. Maximum cases of low pressure and long-wave perturbations were examined.

Ya. B. Zel'dovich (1962) examined the possibility of solving the problem of formation of stars and galaxies by calculation of phase transitions during the formation of initial perturbations. His detailed consideration of this question (1963) showed that this path does not lead to a positive result. I. D. Novikov (1964) obtained positive result by assuming that small fluctuations of density, accompanied by small fluctuations of metrics, appeared on a sufficiently early stage of expansion of a uniform universe — at densities many times greater than nuclear. Now it is possible to explain the formation of objects of various scale in outer space up to clusters of galaxies of the size of hundreds of megaparsecs.

A. D. Sakharov (1965) assumed that initial heterogeneities appear as a result of quantum fluctuations of cold substance consisting of baryons and leptons at a density of the order of 10^{98} baryons (i.e., 10^{74}g) per 1 cm^3. It was assumed also that with such densities gravitational effects are determining in the equation of state, thanks to which at a certain density of baryons the denseness of energy turns into zero. Theoretical appraisal leads to a value of initial heterogeneity which explains the appearance of clusters with masses of the order of 10^5 to 10^6 solar masses, which is close to masses of globular clusters. (Thus, dimensions of initial heterogeneities are derived from certain initial positions, but will not be selected (as ordinarily) on the basis of the requirement that results agree with empirical data). According to the hypothesis of A. D. Sakharov, gravitational collapse of these primary star clusters leads to the appearance of gas possessing heterogeneities in motion and distribution. Accretion of these nonuniformities leads to the formation of galaxies. According to the proposed hypothesis the spherical component of galaxies consists mainly of clusters of primary stars captured by the gravitational field of a rotating

gas cloud, whereas stars of flat composition are formed from gas.

The above hypotheses of the formation of stars and galaxies assume a "cold" universe.

In contrast to wide-spread ideas of the formation of cosmic objects (stars, galaxies and their ensembles) from diffuse substance (at least initial perturbations appeared at the stage of superhigh density), V. A. Ambartsumyan develops an idea that objects in outer space appear directly from superdense substance, where processes of their formation (including formation of galaxies and their ensembles) continue in this epoch. These ideas are based on analysis of data from observations concerning processes in galaxies and ensembles of galaxies, and interpretation of these data as evidence of their nonstationarity (1958, 1964). V. A. Ambartsumyan assumed also (1962) the presence of a community between phenomena of nonstationarity of systems of galaxies on one hand, and the phenomenon of expansion of the metagalaxy on the other.

I. D. Karachentsev (1964), calculating the number of galaxies up to different angular diameters, concludes that the result of this count gives an independent confirmation of the idea of continuous formation of new galaxies. I. D. Karachentsev (1966) found also that the degree of nonstationarity of different systems of galaxies is higher the greater the luminosity of the system, and that this correlation extends to the metagalaxy. The last result was interpreted as confirmation of V. A. Ambartsumyan's idea of a connection between the phenomenon of nonstationarity of systems of galaxies and expansion of the metagalaxy.

A hypothesis coordinating the idea (V. A. Ambartsumyan) of formation of objects in outer space directly from superdense substance with relativistic cosmologic theory was proposed by I. D. Novikov (1964). According to this hypothesis, quasars are lagging in expansion nuclei-parts of the expanded uniform isotropic universe.

Initial linear dimension of such nuclei are less than their gravitational radius. Moreover, in proper time of nuclei there is no delay in expansion. For the outside ovserver nuclei can appear at a different time. The author of the hypothesis derived an exact solution of gravitational equations describing a cosmologic model with lagging nuclei and their subsequent expansion. The possibility of formation of such nuclei at the stage of compression which could precede expansion was examined also.

32. As we already said, in relativistic cosmology the photometric paradox removed by reference to weakening of the surface brightness of radiating objects by the megagalactic red shift. Strictly speaking, in models expanding from singularity, removal of the photometric paradox can be examined as a result of the finiteness of the time of existence of objects whose radiation is being considered, or which is equivalent, the finiteness of their number. However, removal of the photometric paradox does not remove the question on intensity and spectrum of metagalactic radiation. This question was examined by A. G. Doroshkevich and I. D. Novikov (1964): under different assumptions they calculated the spectrum and intensity of metagalactic radiation created by stars and radiation sources in a uniform isotropic universe. In a "hot" universe onto this spectrum should be imposed the spectrum of plank radiation, constituting thermal radiation of prestellar matter transformed in the process of expansion: radiation remains equilibrium, where its temperature changes in inverse proportion to scale factor, and density of radiation changes in inverse proportion to the fourth power of the scale factor. For the temperature of this relic (residual) radiation under different assumptions earlier (G. Gamov) values from several to thirty degrees Kelvin were obtained, which corresponds to radiation which in the centimeter radio frequency band should be tens of times more intense than the radiation of radio galaxies. A. G. Doroshkevich and I. D. Novikov indicated that observations in the range from 0.06 to 30 cm must give a check to the hypothesis of the "hot" universe.

Such radiation later (1965) was discovered by the American researchers A. Penzias [Translators Note: exact spelling not found] and R. Wilson. In intensity and spectral composition it constitutes isotropic equilibrium radiation, the absolute temperature of which is 3°.

Discovery of this radiation (radio background) was interpreted (R. Dikke [Translators Note: exact spelling not found] and others) as confirmation of the hypothesis of the "hot" universe. From the point of view of this hypothesis metagalactic radiation was interaction with substance up to the recombination of hydrogen, occurring at around 3000° K. Consequently, the temperature of this radiation in the epoch when its interaction with substance had practically ceased, equaled approximately the shown value, i.e., was a thousand times higher than presently. This means that the scale factor was as many times less, and the metagalactic density of substance a billion times more than at present.

Ya. B. Zel'dovich and I. D. Novikov (1967) showed that another explanation of the origin of this equilibrium cosmic radiation as a result, in the end of energy release in space bodies on a certain stage of expansion of the metagalaxy is extraordinarily improbably, since it requires a rapid release of a considerable portion of nuclear energy — assuming its subsequent re-emission by dust in the form of equilibrium radiation. As method of confirming the correctness of interpretation of the discovered radiation assuming the "hot" universe shown (Ya. B. Zel'dovich, 1966) observation of the neutrino was pointed out: from the early stage of expansion, in which density of substance had to be 35 orders higher than now, we have had to reach relic thermal neutrinos where (temperature by this epoch dropped to 2°K). But their detection requires a million times more accuracy in experiments.

Obviously, the correctness of the accepted explanation of the origin of radio background, predicted on the basis of the hypothesis of the "hot" universe expanded from singularity, is connected with the correctness of hypothesis. However in reality the correctness

of the explanation of the development of the radio background still does not indicate correctness of the actual hypothesis, more exactly, does not signify correctness of the theory that expansion began from singularity: after all, from the accepted explanation it follows only that in the past the density of substance was larger than now by at least a billion times. But on this base one can hardly affirm that in an earlier epoch it was many times more.

33. So far, touching on the origin of objects in outer space, we have talked almost only about work prior to the discovery of the isotropic radio background. After that discovery certain variants ir the position of the problem underwent essential changes, partly because of direct corollaries to the presence of a radio background, partly due to tis treatment as evidence of the validity of the hypothesis of a "hot" universe. In particular, Ya. B. Zel'dovich and I. D. Novikov (1966) criticized the fact that hypothesis of lagging in expansion of nuclei. The essence of their remarks was that on early stages of expansion of the universe the existence of bodies whose linear dimensions were less than their gravitational radius should be accompanied by strong accretion of radiation. If further calculations should show that this accretion is catastrophically great, then the hypothesis would contradict observations.

In order to explain the formation of such thickening as clusters of galaxies as a result of disturbance in gravitational stability of the gaseous environment, it is necessary to assume that it had a very high temperature. This condition is fulfilled on early stages of expansion of a "hot" universe. But here gas almost is completely ionized and its density is high. Consequently, it is opaque, i.e., strongly interacts with radiation, whose density also is very high. Adiabatic perturbations, during which substance is compressed together with radiation, do not grow, since elasticity of the mixture of substance and radiation is great because of the radiation, whose pressure exceeds the pressure of the substance (more exactly, the critical mass at which disturbance of gravitational stability is possible, is too great). But isothermal perturbations can grow during which only substance is compressed (more exactly, for

them critical mass is much less). However, due to strong interaction of radiation and (opaque) substances, such perturbations grow slowly. Interaction of metagalactic substance with radiation becomes immaterial when ionized gas recombines (becomes neutral), consequently, it becomes transparent. L. M. Ozernaya (1964) arrived at this conclusion. She also gave a theory of the heat balance of expanded metagalactic gas for different variants of heating and cooling. She expressed the idea of the heating of recombined gas due to the dissipation of turbulent motions, and also explosions of rapidly evolving objects of quasar type (see also section 34). The role of initial conditions in the formation of galaxies of different morphologic types was examined.

Formation of stars and galaxies as a result of gravitational instability apparently could occur only after recombination of metagalactic gas. But this gas was cold and critical masses composed only 10^5 solar masses. Consequently, in order to explain formation of galaxies, it is necessary to assume that after the epoch of recombination the heating of metagalactic gas and its ionization occurred. Now, however, both density of gas and density of radiation have become much less, and consequently, the interaction between them is much weaker, so that it does not hinder the growth of perturbations. The question of sources of heating of the metagalactic gas appears.

It is possible to assume that such sources were the explosions of great stars with masses of the order of 10^5 solar masses, i.e., objects whose formation as a result of gravitational instability became possible after recombination of hydrogen, at a metagalactic density of the order of 10^{-21} g-cm^3. After the heating up of metagalactic gas large heterogeneities were formed from which clusters and galaxies appeared. Such a hypothesis of the formation of galaxies was proposed by A. G. Doroshkevich, Ya. B. Zel'dovich and I. D. Novikov (1967); for explosions of hugh stars, see G. S. Bisnovatyy-Kogan (1967).

34. Current density, state and composition of intergalactic substance presents interest not just in connection with the origin of stars and galaxies. First of all it is an important question about metagalactic density, inasmuch as it determines the retardation of expansion, and also the sign of the curvature of space. Critical density, i.e., that value of contemporary density at which (assuming equality to zero of the cosmologic constant) curvature is equal to zero, is tens of times more than we obtain considering mass concentrated in the galaxies. (If density is lower than critical, curvature is negative; if density is higher than critical, curvature is positive.) The state and composition of intergelactic substance is important both in connection with processes on early stages of expansion and the composition of presteller substance, and in connection with physical processes in intergalactic substance.

B. M. Pontekorvo and Ya. A. Smorodinskiy (1961) examined the possibility that the density of energy of the neutrinos and antineutrinos in the universe in this epoch is comparable with greater than density of energy connected with the rest mass of hydrogen. The hypothesis that observable charge asymmetry is the result of the separation of substance from antimatter due to fluctuations in a charged-symmetric universe. This fluctuation hypothesis requires that in the epoch when fluctuation occurred the density of neutrino and antineutrino energy was many orders higher than the density of energy of the nucleons. Upon expansion, the density of neutrino and antineutrino energy falls more rapidly than the density of nucleon energy (these densities are in inverse proportion, respectively, to the fourth and third power of the scale factor). Therefore this hypothesis does not contradict current data if one were to assume that fluctuations leading to separation substance from antimatter occurred in an epoch when the scale factor was many orders less than at present.

Ya. B. Zel'dovich and Ya. A. Smorodinskiy (1961) assumed that at contemporary values of the Hubble parameter and at a density larger than $2 \cdot 10^{-28}$ g-cm^{-3}, the age of the universe would be in any case less than the age of the earth and radioactive

elements. Hence it was concluded that this density must be the upper limit of the total density of all forms of matter. This gives an upper limit to the density of neutrinos and gravitons, where the sensitivity of other methods of their detection is much less.

In connection with appraisals of average metagalactic density, the conclusion of I. D. Novikov and L. M. Ozernaya (196?) that the total mass of collapsing stars in the galaxy in any case is less than the mass of visible matter is of great interest. The work of Yu. P. Pskovskiy (1965), containing a determination of the mass of cluster of galaxies in Coma Berenices by a new method – by orbital inversion of its peripheral galaxies (instead of peculiar notions) – is also of interest. Average metagalactic density (when the inverse Hubble parameter is 10 billion years) is $7 \cdot 10^{-30}$ g-cm^{-3}.

Assuming that metagalactic substance consists of gas (mainly hydrogen) V. L. Ginzburg and L. M. Ozernaya (1965) analyzed its heat conditions. Cooling of gas due to radiation and general expansion and heating of gas due to dissipation of energy of plasma waves formed by cosmic rays appearing during the explosions of galaxies and radio galaxies were considered. The basic mechanism of cooling at present is adiabatic expansion. According to conclusions of the authors, gas has been almost completely ionized. This circumstance explains why a large part of metagalactic substance so far has escaped observations.

An attempt was made to detect ultraviolet radiation of intergalactic ionizing hydrogen and helium with the help of equipment on the Soviet interplanetary automatic station "Venus-3" in 1966 by V. G. Kurt. From the negative result of this attempt Kurt and Syunyayev deduced that metagalactic density, in any case (if one makes no special assumptions about the temperature of gas) is lower than three times critical (1967).

N. S. Kardashev and G. B. Sholomitskiy (1965), estimating maximum distance and corresponding value of the magnitude of red shift ($\Delta\lambda/\lambda$), up to which observation of extragalactic objects is possible, concluded that it can be determined by Thomson scattering of radiation in the intergalactic medium. This value, depending on density of medium and type of model, lies between 3.5-7. (It follows from this that it is possible to observe past metagalactic objects only within limits of the epoch during which the scale factor grew 4.5-8 times. These estimates pertain also to dimensions of the region and to duration of the epoch in application to which is possible to speak about observed — apparently accurate to tenths of a percent — isotropy of the radio background.)

Composition of prestellar substance, i.e., relative abundance of hydrogen and helium, depends on rate of expansion in the epoch of their formation. This rate in turn depends on the isotropy or anisotropy of expansion. In a uniform isotropic model the contents of helium should be 30%. In anisotropic models the portion of helium can be larger and less (up to almost complete absence; depending upon the character of anisotropy.

Ya. B. Zel'dovich, I. D. Novikov and R. A. Syunyayev (1966) offered methods of investigation of intergalactic helium and indicated cosmologic value of possible results, inasmuch as the contemporary contents of helium in the intergalactic medium, first, depends on the character of expansion on its early stages and, secondly, strongly affects heat balance and state of ionization of gas. Therefore an investigation of intergalactic helium will allow determination, first, of the degree of isotropy of expansion on early stages, i.e., at an average density of the order of 1 $g{\cdot}cm^{-3}$ (when formation of hydrogen and helium occurred), and, secondly, of contemporary density and the state of intergalactic gas. Syunyayev (1966) examined possible sources and methods of observation of the isotope of helium with atomic weight 3 and deuterium, formation of which constitutes an intermediate stage in the changing of hydrogen into helium. Doroshkevich and Syunyayev (1967)

calculated the thermal balance of the intergalactic medium and stressed the important role of helium in its cooling.

It is easy to see how the statement of the questions changed. Earlier they assumed that the material for stars had to be pure hydrogen, and theory of a uniform isotropic universe had to explain its formation — this caused difficulties. Now the question about chemical composition of prestellar substance is being revised, and cosmologic theory can explain any relative contents of hydrogen and helium at the cost of rejecting the assumption of isotropy. This involves, first, an increase of interest toward the theory of an anisotropic (at least a uniform) universe and, secondly, inevitability of reconsideration of the growth of old objects in outer space and the duration of expansion.

We note also that the idea that formation of hydrogen and helium occurred at the beginning of the present expansion and besides in the scales of the whole metagalaxy (and not on one of the preceding stages and not inside structural formations of smaller scale), is inherited from the theory of a uniform isotropic universe, and the validity of this simple idea is still unproven.

35. The work of B. M. Pontekorvo and Ya. A. Smorodinskiy (see section 34) examined one of the explanations of the observed charge asymmetry of matter. Assuming that in the part of the universe observed by us along with substance there exists also antimatter, N. A. Vlasov (1964) offered an optical method of its detection.

Proceeding from the fundamental character of properties of symmetry, G. I. Naan (1964) assumed that the universe possesses full symmetry and consists of world and antiworld, indiscernible in intrinsic properties (so that it makes no difference what part of the universe is considered world and what part antiworld). Antiworld according to Naan differs from world by not only replacement of particles by antiparticles, but also space (mirror) reflection

and time reversal. Mass, energy and so forth, integral quantities in world and, accordingly, antiworld can change, but in the universe consisting of world and antiworld they remain (in sum) equal to zero. In this case interaction in the usual meaning between world and antiworld is absent. G. I. Naan indicates that in connection with the possibility of appearance of mass and energy in each of the two parts of the universe, from the point of view of the proposed hypothesis all phenomena distinguished by colossal energy release present interest (cosmic rays, supernovae, quasars, nuclei of certain galaxies, radio galaxies), and also the beginning of expansion of the metagalaxy.

The view that charge asymmetry is possessed by the whole universe is more widespread. According to ideas of Ya. B. Zel'dovich and I. D. Novikov (1966), charge asymmetry of the universe in this epoch is the result of the same asymmetry in the epoch of compression (preceding the observed expansion), in which at density of the order 10^{-30} g-cm^{-3}, as a result of the usual nuclear reactions (for example, in cosmic bodies) energy of the order of 10^{16} erg-g^{-1} was liberated. On approaching singularity, at the expense of generation of particles and antiparticles with a high density of energy, almost full symmetry is attained. With the beginning of expansion and fall of density of energy, as a result of annihilation of particles and antiparticles the former asymmetry appears.

To explain the observed charge asymmetry A. D. Sakharov (1967) assumes that in the superdense state of a "hot" universe, in particular the laws of preservation of baryons and muons are disturbed (instead preservation of a combined baryon-muon charge is assumed).

36. According to ideas developed by Ya. P. Terletskiy (1964), macroscopic deviations from thermodynamics do not contradict the statistics of Gibbs. In particular, the existence in the universe of a "perpetual motion machine of the second kind" with heat sources possessing negative energy and negative temperature is

possible. Disturbance of the causality principle and existence of macroscopic systems with negative time sense is possible. Particles of not only positive but also negative and even imaginary mass can exist.

These general ideas were applied by Ya. P. Terletskiy to the problem of quasars, radio galaxies and other phenomena which are as yet unexplained. The essence of these applications consists in calling on those processes whose possibility emanates from these ideas. In particular, it is indicated that the idea of existence of a new kind of power sources of the type of a perpetual motion machine of the second kind can be used to explain energy release by radio galaxies and quasars.

E. B. Gliner (1965), offering a physical interpretation of certain algebraic structures of energy-momentum tensor, allows that a form of matter is possible for which this tensor is equal to metric multiplied by a constant ("mu"). This matter, called mu-vacuum, macroscopically possesses vacuum properties. We consider the assumption that real vacuum is a mu-vacuum. (Let us note that the idea of speed is not applicable to this form of matter. It is also possible to say that the pressure of a mu-vacuum equals its density of energy with the opposite sign.) A uniform world from mu-vacuum possesses de Sitter metrics. Further E. B. Gliner offers a generalized law of gravitation, expressed by a system 20 equations (in partial derivatives of the second order) in accordance with the fact that the curvature of the space-time continuum is described by 20 quantities. Einstein's law of gravitation expressed by a system of 10 equations results from this generalized law.

B. L. Altschuler (1966) offered a method of recording Einstein's equations in integral form using the covariant Green's function. For a particular selection of the equation for this function the integral form is a covariant recording of the Mach principle, i.e., principle of reality of inertia. This principle

becomes equivalent to the requirement that Einstein's equation be valid in integral form. It is shown that, in particular, uniform isotropic cosmologic models are incompatible with the proposed form of the Mach principle.

A variant of the theory of a change of world constants, founded on ideas of Dirac (see section 5), was proposed by K. P. Stanyukovich (1962). According to this variant the total mass of particles is preserved, gravitational constant and number of particles (nucleon) grow with time, but the planck constant, charges and mass of particles decrease. Decrease of masses of elementary particles is treated as the result of their irradiation of gravity waves. The right side of Einstein's equations is subjected to modification (generalization). We consider generalization of Fridman models corresponding to changeability of the gravitational constant and modified equations of gravitation (1963). Later K. P. Stanyukovich (1966) assumed the existence of stable particles — planckions, for which contemporary values of mass, radius and density coincide with values of quantities of the same dimension, built from Planck's constant, gravitational constant and the velocity of light (respectively $1.1 \cdot 10^{-5}$ g, $1.3 \cdot 10^{-33}$ cm, 10^{95} g-cm^{-3}). Connecting this hypothesis with his own variant of the theory of changeability of constants, Stanyukovich assumes the existence of closed particles also with other defined values of mass, dimensions and density.

The ideas of Stanyukovich (radiation of elementary particles, etc.) caused objections and polemics between it, on one hand, and Ya. E. Zel'dovich and Ya. A. Smorodinskiy, on the other (1966).

M. A. Markov (1966) examined the characteristic masses $m_0 = (\hbar c/\gamma)^{1/2}$ and $m_1 = e/\gamma^{1/2}$ as possible maximally great values of the mass of elementary particles (maximona). These values are of the order of 10^{-5} and 10^{-6} g respectively.

The mass ratio of electron (m) and neutron (M) is approximately equal to the ratio of coupling constants for electromagnetic $(e^2/\hbar c)$ and

and strong ($g^2/\hbar c$) interactions. Relying on this empirical relationship, D. F. Kurdgelaidze (1964) introduces universal mass (equal to $M\hbar c/g^2 = m\hbar c/e^2 = 1.25 \cdot 10^{-25}$ g) and mass connected with gravitational interaction (equal to $\gamma m_0^2/\hbar c = 4 \cdot 10^{-66}$ g), and using them examines certain empirical relationships between microphysical and metagalactic parameters.

The idea of an analogy between the metagalaxy and any particle which on the external side is elementary, was developed by G. M. Idlis (1965). He also examined causal stipulation of three-dimensional space and the universal character of the law of universal gravitation (1965).

Theories of the spontaneous generation of matter and changeability of constants were criticized by Ya. B. Zel'dovich (1962). One basic idea of this criticism can be pleased in the following way. The rate of generation of matter should depend on some quantities characterizing the state of the universe, for example on density. If the rate of this process depended on density in a given point, it would be noticed even on the earth. If, however, we assume that this rate depends on the average metagalactic density, we will contradict the local character of contemporary physics. Empirical agreements between microphysical constants and metagalactic parameters also carry nonlocal character, and, consequently, the idea of their preservation with time, i.e., changeability of constants, also contradicts the local character of contemporary physical theories. These theories contradict also basic laws and theories of contemporary physics, such as the law of preservation of the baryon number or a special and general theory of relativity. Above results concerning special questions of cosmology and the theory of gravitation were examined. However, the number of authors discussed general, philosophical or methodologic, questions. The number of these authors can also include V. A. Ambartsumyan, A. F. Bogorodskiy, G. M. Idlis, V. M. Kazyutinskiy, E. Coleman, V. A. Krat, G. I. Naan, K. F. Ogorodnikov, M. S. Eygenson and other.

We saw that as a result of the discovery of new empirical facts during the last few years the tendency toward that division of cosmology which studies the physical state of masses and its change with time was strengthened. In this cosmology in ever greater measure relies not only on astronomical, but also on physical facts, and not only on the theory of gravitation, but also on other physical theories. Thereby, remaining as a division of astronomy and preserving its specific character, connected with the inevitability of far-reaching generalizations and with the necessity of high mathematical rigor, cosmology ever more joins the general flow of the physical sciences. It is not excluded that this tendency will lead to the transformation of all cosmology. But the creation of a new basic physical theory, which we conditionally called the single physical theory would have still more far-reaching consequences. It is very probable also that only within its framework will discovered facts obtain correct explanation.

The author considers it his pleasant duty to express gratitude to Academician Ya. B. Zel'dovich, Professors B. V. Kukarkin, S. B. Pikel'ner, L. S. Polak, Senior Scientific Colleague I. D. Novikov and Candidate of Physical and Mathematical Sciences L. M. Ozernom for numerous important remarks.

THE STUDY OF OUTER SPACE USING ARTIFICIAL EARTH SATELLITES AND ROBOT SPACE STATIONS

The need astronomers have for equipment able to lift instruments beyond the limits of the terrestrial atmosphere is due first of all to the absorption of radiation by different components of the atmosphere. Almost one hundred years ago absorption of the ultraviolet end of the spectrum with wavelengths shorter than 3000 Å was revealed. This absorption is connected basically with ozone forming in the atmosphere a rather narrow layer whose maximum is located at around 30 km. In the region of wavelengths shorter than 1800 Å and up to 800 Å absorption is determined by molecular oxygen, but in the more short-wave region of the spectrum absorption is determined by atomic oxygen and molecular nitrogen. Water vapors intensively absorb ultraviolet radiation; however, the amount of water vapor rapidly decreases with height, fading away at heights exceeding 30 km.

In the infrared region of the spectrum absorption is first by water vapors, carbon dioxide and only then by molecular oxygen. Finally, in the region of radio waves absorption is connected with the ionosphere, which makes the region of wavelengths usually inaccessible for observation more than 30 m. In the submillimeter range molecular absorption becomes essential, especially absorption connected with water vapors and carbon dioxide.

To these purely spectral "troubles" which are caused by the atmosphere is added one more — tremor. It decreases the penetrating

force of telescopes, "smearing" the image of the star into a disk, makes inaccessible for observations small details of the planets, moon, and sun.

The magnitude of vibration strongly changes from night to night and very significantly depends on the location of the observatory. On an especially good night for observations the stellar disk determined by vibration attains a magnitude a little smaller than 1". This exceeds by many times the theoretical resolving power of a telescope of even modest dimensions. Therefore a telescope of very high quality which does not introduce noticeable abberations, beyond the bounds of the atmosphere could in principle allow a resolution much smaller than 1", for a sign of only 0.5 m. However, one should not forget that the system of orientation of such a telescope should ensure corresponding precision, i.e., during the time of observations the telescope should not shift by a magnitude exceeding 0".1, which as yet is still unattainable.

Thus, the extension of a telescope beyond the limits of the atmosphere with necessary spectral and photometric equipment can bypass all those difficulties mentioned above. Furthermore, there is a number of problems which cannot be overcome even with the equipment on the surface of the earth. For example, photographing the reverse side of the moon, study of the magnetic field of the planets,[1] analysis of meteoric substance directly in outer space, etc. In light of what was said it is doubtful whether the automatic stations on the surface of the planets or approaching them at close range should be stressed. The value of information attained in this way can be exceeded only by landing a man on the surface of the moon, and then the planets. In this case study of the planets will become an independent science, separated from classical astronomy.

Direct study of outer space starts approximately from heights of 20-30 km. The most accessible means of achieving these

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[1]It is true that radio astronomy provides certain possibilities in this direction.

comparatively low heights are aerostats, into whose gondola can be placed the necessary equipment. This method has two basic advantages: relatively small cost of the experiment and possibility of returning equipment to the earth, which, thus, can be used repeatedly. Additional equipment placed on the aerostat consists usually of batteries to feed all drives of the servomechanism (for guilding to the photographed object) and a system of thermal control. Sometimes it is necessary to place in the gondola a command radio line system to control equipment from the earth, and also a telemetric system for operational transmission of data to a receiving ground station. One of the main results of such balloon astronomy is obtaining photographs of the solar surface with very high resolution, reaching 0".1 and spectra of the planets Venus and Mars to exclude the influence of lines of the terrestrial atmosphere.

Recent results of the study of such spectra (United States) showed that the quantity of molecular oxygen in the atmosphere of Venus is extremely minutely.

In the USSR at the end of the 1950's aerostats were used in the investigation of terrestrial radiation in the infrared region of the spectrum, in the study of vertical distribution of ozone and certain other works. In November, 1966, the USSR launched to a height of 20 km an aerostat with astronomical observatory weighting more than 7.6 t.

The possibility of complex scientific experiments on artificial earth satellites and rockets is ensured by the high reliability of the launch systems. Only thanks to the unfailing work of carrier rockets, on-board telemetering systems, control systems, and also the flight safety ground complex, the service for treating arriving information and many others, is it possible to obtain full value scientific material. High reliability and continuity in work are many times more necessary during manned flights in the Cosmos.

Naturally flights of Soviet artificial earth satellites and robot space stations were preceded by comprehensive preparation. It

is difficult, of course, to even enumerate those sciences and branches of technology which made possible the fast growth of domestic cosmonautics: 1957 – first artificial earth satellite, three and a half years later – first astronaut in the world, four years after – astronaut in pressure suit enters open space! Work in the region of rocket engine design, and research in the aerodynamics of superhigh speeds were conducted in our country even in the 1930's. We remember studies by the GLD (Gas-dynamic laboratory) and GIRD (Group for the study of jet propulseion), already the property of history. Still earlier stellar voyages became the object of scientific study by one of the most brilliant enthusiasts and zealots of science, K. E. Tsiolkovskiy. In region of development of mathematical methods of rocket flight calculation much has been done by I. V. Meshcherskiy and his pupils. A great contribution in calculation of routes of flights around the earth, to the moon and planets of the solar system has been introduced by our astronomers.

For the first time real prospects of investigations with rockets lifting scientific instruments to heights of several tens of kilometers were outlined at the First All-Union Conference on Study of the Stratosphere in 1934 and at the All-Union Conference on Application of Rocket Vehicles to Mastering the Stratosphere in 1935. At these conferences it was decided to unite the efforts of scientists and engineers working on the creation of rocket engines, scientific equipment, etc., in many cities of the Soviet Union. Among the pioneers of rocket building was the recently deceased Academician Sergey Pavlovich Korolev, whose name recalls outstanding successes of Soviet cosmonautics.

The stage of direct study of outer space began from the use of high-altitude rockets, which became possible only after the second world war. From the middle 1950's a great complex of investigations using geophysical rockets to study the structure of the terrestrial atmosphere was carried out in the Soviet Union. It is necessary to note that these launches attained a recordbreaking height for a single-stage rocket (516 km).

To decrease gas generation from the surface of a rocket the Soviet Union used a releasable container on which besides scientific equipment was a telemetric system for transmission of obtained data to the earth. During these experiments the container with the expensive equipment descended by parachute to earth. For high-altitude launches another type of oriented container was used, called the "high-altitude geophysical automatic station " (VGAS). The VGAS is a sphere 1 m in diameter and weighing around 400 kg, equipped with a three-axial space autostabilization system and a multichannel high-query telemetry system. This is placed in the nose of the rocket and enclosed by two conical shields. After leaving the dense layers of the atmosphere the VGAS is ejected with extra velocity with respect to the rocket (around 1 m/s). The station flies autonomously, attains the peak of its trajectory and drops, continuously transmitting scientific information. In the upper part of the VGAS is a large number of illuminators parallel to the equatorial belt of the sphere. In them are the sensors of the scientific equipment to study composition and density of the terrestrial atmosphere, brightness of the sky at various heights, solar ultraviolet and X-radiation, distribution of neutral hydrogen in the upper atmosphere of the earth, cosmic rays, radiation belts of the earth, etc. Analogous high-altitude rockets in the USSR carried out medical and biological experiments.

Possessing great merits, high-altitude geophysical rockets, however, ensure an experiment length of not more than 10-15 minutes. This limitation does not permit complete degasification of the surface of the container, that complicates treatment of material, and frequently makes it simply impossible. Moreover, it is extremely difficult to study with geophysical rockets such short-term phenomena as, for example, solar flares. A certain compromise is a combination of rocket with aerostat. An aerostat with suspended small research rocket is launched to 20 km. Upon detection of a solar flare a command from earth launches the rocket, which in several minutes attains a height from which it is possible to carry out observation of short-wave radiation. Such a system was used in the United States to study X-radiation of the sun.

A new era in development of extra-atmospheric astronomy and geophysics began 4 October 1957, when the USSR launched the first artificial earth satellite in the world. Artificial earth satellites permit considerably increasing the duration of an experiment, and also investigating latitudinal and longitudinal effects of the structure of the terrestrial atmosphere, radiation belts of the earth, cosmic rays, etc. After the first artificial earth satellite in the USSR a second and then a third was put into orbit. At this time the total number of artificial earth satellites and rockets launched in the USSR exceeds 200 and continues to grow rapidly.

Both in our country and in the United States for scientific purposes artificial earth satellites of different types have been created. To supply equipment of "long-lived" artificial earth satellites – with a lifetime of more than a month – solar batteries are used in combination with chemical sources of current, storage batteries, whereas for short-lived artificial earth satellites only chemical sources of current are used. All satellites have a system for determination of orbital parameters, telemetric system, and also a heat regulation device. When necessary the artificial earth satellites have a command radio line for start-stop operation of separate subassemblies of equipment from the earth; frequently satellites are equipped with very complex program-time devices for autonomous fulfillment of scientific problems. On the whole every artificial earth satellite is a very complex aggregate of radio electronic equipment of high reliability. This equipment should transfer vibrations and overloads of the power phase of trajectories, a great drop in temperatures with continuous functioning frequently over many months. Furthermore, it has the following requirements: low weight, compactness and economy, especially in the case of solar battery feed. Before launching the artificial earth satellites pass a lengthy warmup and check, partially simulating conditions of launching and flight in space.

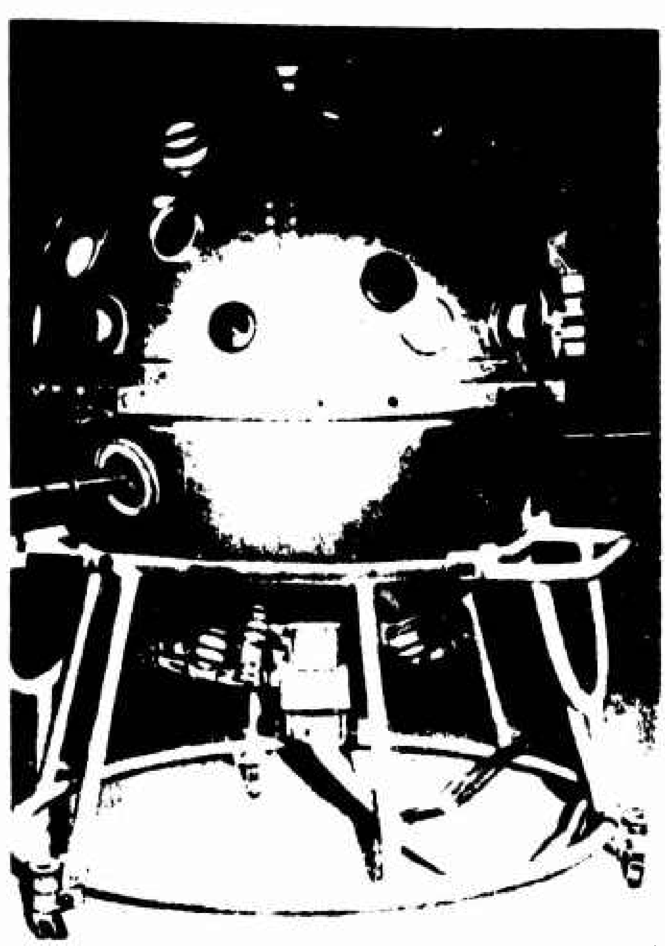
Launching of a single-stage geophysical rocket.

The weight of an artificial earth satellite depending upon its assignment fluctuates from several kilograms to tens of tons. Examples of heavy artificial earth satellites are satellites of "Proton" type and satellite spaceships. Small satellites intended for a limited number of problems are the Soviet satellites of Cosmos series, of which already more than 170 have been launched. Usually satellites are put into circular or weakly elliptic orbits; however, sometimes when necessary the orbit is highly elongated with perigee of the order of 300 km and apogee around 100,000 km. An example of such a satellite is the Soviet artificial earth satellite "Electron." With this launching one carrier rocket put into orbit two artificial earth satellites: one on a low, almost circular orbit and the other on a prolate orbit. Such selection of trajectories permits simultaneously recording events near the earth and at distances of the order of several tens of terrestrial radii. Especially important is a similar system for recording magnetic phenomena and connected fluxes of charged particles in radiation belts of the earth. Contemporary powerful carrier rockets can ensure putting simultaneously several satellites both on identical and various orbits. In the Soviet Union there already have been such launches, where the number of satellites reached five. This method gives researchers new possibilities for carrying out various scientific experiments simultaneously in different regions of circumterrestrial outer space.

The scientific equipment on artificial earth satellites varies extraordinarily: complex aggregate of manometers, mass spectrometers of neutral composition – to study of neutral particles; mass ion spectrometers, intended for the study of density of the atmosphere and its variations, chemical composition, etc.; equipment for the study of radiation belts of the earth and cosmic rays, which consists of geiger counters, ionization chambers and Cerenkov counters, and also different types of plasma probes and charged particle traps. Certain satellites had magnetometric equipment to measure the magnetic field strength of the earth.

The first spaceship launching with an astronaut (Yu. A. Gagarin) on board was carried out in the Soviet Union 12 April 1961. The Soviet Union launched multiseater satellite vehicles of the Voskhod type, and astronaut A. A. Leonov was the first to go into outer space in a self-contained pressure suit. The first such launchings are finished for launching flying laboratories with scientific personnel on board.

However, artificial earth satellites cannot solve all problems in the study of the planets, the moon and the interplanetary medium. A more complex investigation was the launching of a robot space sta ion for photographing the reverse side of the moon. The first launchings (Luna 1, January 1959 and Luna 2, September 1959) showed the absence of a sufficiently strong magnetic field near the moon and gave much valuable information relatively to circumterrestrial outer space. The launching of Luna 3 was 4 October 1959. The station was put into an orbit passing near the moon, subsequently approaching 10,000 km to the earth. On board was a phototelevision



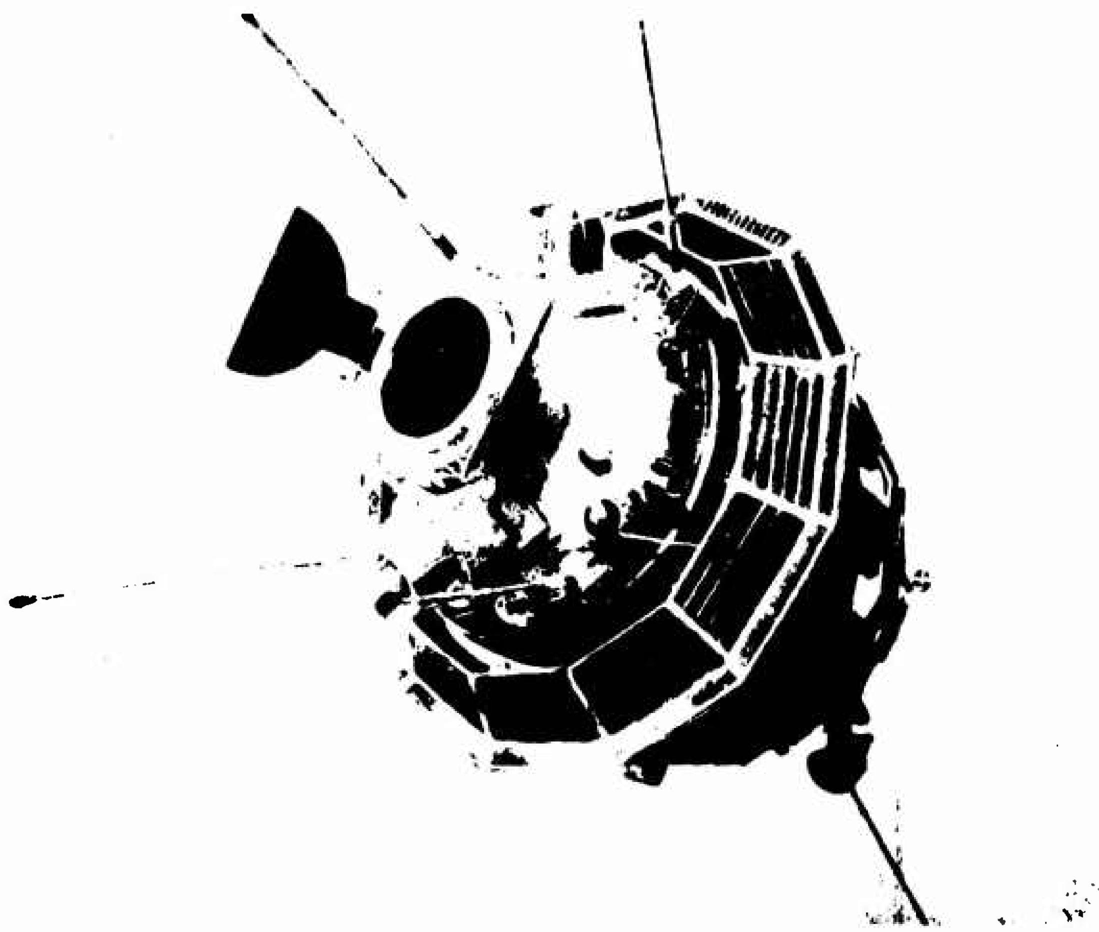
High-altitude geophysical robot space station.

device with two objectives (F_1 = 200 mm and F_2 = 500 mm). While circling the moon a special tracking system oriented the station on the moon and held it in this position throughout the photographing. During photographing the exposure was automatically changed, which permitted separating on photographs sections of various illuminance. After photographing the film was treated on board, dried, and then sent to a transmitting device with a small electron-beam tube used to scan the negative (television transmission of the photograph by lines). The beam transilluminating the negative was focused then on the photocathode of electron multipliers whose signal was transmitted to earth. Here the signal was recorded on magnetic film. In such a way the earth received a great number of photographs. Subsequent thorough treatment permitted composing a map and cataloging formations on the reverse side of the moon. Since the part of the lunar surface visible from the earth had already been photographed, the coordinates of craters earlier not observed could be tied in to the general map of the moon.

First pilot-astronaut in the world Yuriy Alekseyevich Gagarin.

The Soviet Union launched the robot space station Zond 3 18 July 1965. The equipment on it, intended for tuning the systems ensuring flight of the objects over many months, helped to solve a series of important problems, the most important of which was detailed study of the reverse side of the moon. Phototelevision equipment, essentially improved as compared to 1959, during flight past the moon at approximately 10,000 km ensured photographing and then transmission to earth of many high-quality photographs of the part of the reverse side of the moon which was not photographed in 1959. They show details only a few kilometers in size. Similar resolution is achieved for the visible side of the moon with the best telescopes on the earth. Thus, practically the whole surface of the moon invisible from earth is included on the map.

An outstanding success of Soviet cosmonautics is the soft landing on the moon's surface by the robot space station Luna 9,

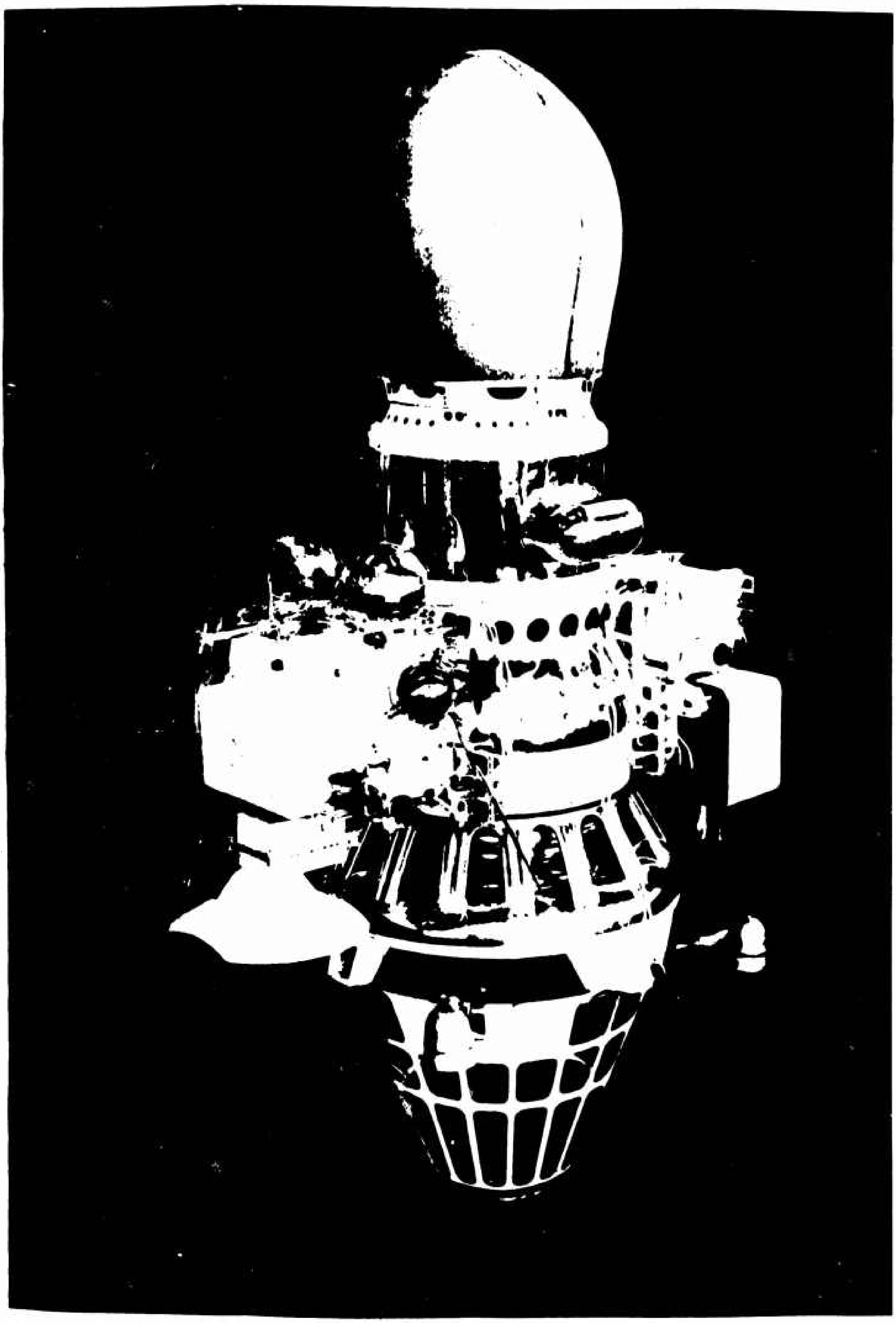


Robot space station (4 October 1959 such a station first photographed the invisible side of the moon).

launched 31 January 1966. The station safely "mooned-in" 3 February at 2145 in the region of the Ocean of Storms, at a point with selenographic coordinates 7° N, 64° W. It was equipped with a phototelevision system for transmission of an image of the environments of the landing site. An image of a panorama embracing 360° in azimuth and several tens of degrees in height was sent. Resolution on all photographs was extraordinarily high: near the station details of the size of a few millimeters were distinguished. The panorama was transmitted four times at different angles of elevation of the sun above the lunar horizon. The basis conclusions which can be made from analysis of the transmitted photographs are: first, the lunar ground is strong enough to hold a spaceship; secondly, the surface of the moon has a hard cover, but not dust, as was assumed by many scientists only a few years ago; thirdly, radioactivity of the lunar surface is low.

Realization of the first soft landing on another celestial body in the world is a great success of Soviet science and technology. This is the result of systematic work on the creation of heavy rockets, able to send into orbit to the moon a station weighing more than a ton, on the designing of a complex aggregate of radio electronic equipment to determine moment for activating the retrorockets and the necessary brake momentum. The successful landing was preceded by preliminary launches to adjust the separate systems ensuring a lunar impact of the container with the equipment at not more than several meters per second.

It is necessary to note also the successful launching of automatic stations of the Ranger type with television cameras on board in the United States in 1964 and 1965. On approaching the moon the equipment continuously transmitted to earth a television image up to the moment of impact of rocket against lunar surface. From a height of less than 1 km it was possible to register details around 1 m in size. Certainly, a very small section of the lunar surface was photographed.



Lunar rocket delivering to the moon the robot space station Luna 9 and ensuring its soft landing on the lunar surface.

Robot space station Luna 9.

Let us stop, finally, on interplanetary robot probes launched to planets of the solar system. Such stations in the USSR were Venus 1, Venus 2, Venus 3, Venus 4, Mars 1, Zond 1, Zond 2, Zond 3; in the United States – stations of the Mariner and Pioneer type. Probably these apparatuses are the most complex of all the series of space rockets. After all, a flight to Venus lasts more than three

and to Mars more than seven months. During flight the station autonomously or on command from earth should fulfill numerous operations: correction of trajectory (sometimes double), orientation to the sun for charging storage batteries from solar batteries, orientation on earth for transmission of information with a highly directional parabolic antenna. Upon approaching the designated planet, the space station is oriented on the planet and conducts the necessary scientific investigations. Then after the pass these data are transmitted to a receiving ground point, where transmission of information obtained during the time of around an hour can continue for many days. The difficulties in developing such probes are evident: it is necessary to realize many-month, completely autonomous functioning of the most complex equipment, to transmit data hundreds of millions of kilometers.

Flights of such apparatuses will precede the landing of a man on the moon and Mars. Study of the surface of Venus will show whether its surface can be used to land astronauts. If, however, it appears that the surface of the planet has a temperature around 350° and pressure of around 6-10 atmospheres (all data of ground observations favor such conditions), then the study of Venus will for a long time remain the "privilege" of automatic machines. Photographs of the surface of Mars from around 10,000 km taken by the American station Mariner 4 showed that its surface resembles the lunar landscape with mountains and craters. Apparently, Mars never had a noticeable atmosphere and hydrosphere, leading on earth to fast surface erosion. The former spectroscopic estimates of the density of atmosphere of Mars were confirmed, corresponding to the earth's at 30-50 km. Such severe conditions make chances for detection of life on Mars not too great.

Development of Equipment Utilized for Astronomical and Geophysical Investigations

At present it is fairly difficult to separate purely astronomical investigations from geophysical, since, first, it is impossible to make a clear boundary separating the earth and its upper atmosphere

from objects in outer space, and secondly, instruments earlier used only for physical or geophysical investigations could now be used for acquiring information about astronomical objects.

The upper atmosphere of the earth is being investigated most fully at present. Here we will stop on determination of its density and composition. The most exact method of calculating the density of the atmosphere is analysis of the change in parameters of the trajectory of an artificial earth satellite. Of the six elements which characterize in every given moment the orbit of an artificial earth satellite mainly only the major semiaxis a and eccentricity of orbit e are subject to change. For an elliptic orbit basically braking occurs in the perigee, which makes it possible to calculate density of the atmosphere at this height.

The first determinations of density of the atmosphere at such high altitudes were made in the Soviet Union immediately after the launching of the first artificial earth satellite. They showed that density at 200-300 km is much more than assumed earlier. These observations forces examination of the whole theory of structure of the upper atmosphere of the earth. In particular, diurnal variations of density were revealed.

Determination of the orbital elements of an artificial earth satellite requires a great number of observations of its position among stars with exact time referencing. With this goal the Astronomical Council of the Academy of Sciences USSR organized a wide network of stations equipped with standard equipment. At first observations were visual with a small telescope and simple timer. These observations were joined by students of universities, pedagogic institutes and many amateur astronomers in all parts of our country and countries of the socialist camp. The comparatively low accuracy of these observations was compensated by their mass nature and regularity. Photographic and photoelectrical means of observations were developed, essentially increasing the accuracy of determination of coordinates of artificial earth satellites. Improved radio

methods permitted highly accurate determination of the distance from station of observation to artificial earth satellite and the radial velocity.

The United States built special mirror-lens high-transmission telescopes, solving the same problem. Around ten of these telescopes (Becker-Nann system) were placed approximately in the equatorial zone on different longitudes and equipped with a special arrangement to automatically fix the moment of photographing.

To determine density with respect to slowing it is profitable to have artificial earth satellites with large surface and small mass. The problem of optical observations of space rockets is much more complex, since the brightness of the latter is many times less than the brightness of artificial earth satellites. It is sufficient to say that at the distance of the moon a robot space station has approximately 17^m. Observation of such objects, even with the largest telescopes in the world is an extraordinarily complex problem, especially as the robot space station moves in the stars. Since the field of view of a big telescope is very small, observation of a slowly travelling star-shaped object is very difficult if one doesn't know at least approximately its coordinates.

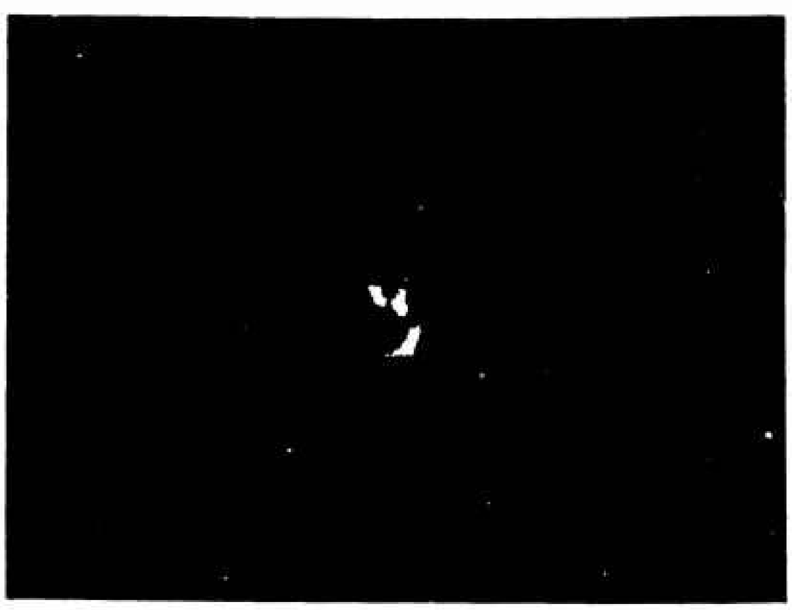
Soviet astronomers proposed and used in practice a very original method of increasing brightness of the robot space stations approximately 100,000 times. The idea uses the phenomenon of resonance scattering of solar radiation by sodium vapors ejected from aboard the space rocket. Every atom of sodium absorbs solar radiation in a narrow band of the orange region of the spectrum and reemits it to all sides. The effectiveness of this process is extraordinarily great. It is sufficient to say that 1 g metallic sodium at 10,000 km gives a cloud brighter than 14^m. At a cloud mass of 1 kg its stellar magnitude is close to 6.

To evaporate sodium it is placed in a metallic container with Thermit, which is ignited at a preset moment by a special program

unit. After successful tests for a high-altitude geophysical rocket in 1958 at 430 km sodium evaporators were placed on two robot space stations launched to the moon: 2 January and 12 September 1959. At around 150,000 km the cloud attained $4^{m}.5$. The observations used specially developed instruments with narrow-band interference light filters centered on the line of sodium glow. The instruments employed image converters needing only several seconds of exposure. In chambers of another type the photographing was done on photographic film of high sensitivity with an exposure ~100 s. Referencing coordinates of the cloud to stars made it possible to definitize the trajectory of the rocket.

Besides purely trajectory problems, experiments on ejection of metal vapors in outer space have an independent astrophysical value.

Thus, for example, the use of ions of metals permits investigating the structure of the earth's magnetic field studying phenomena connected with expansion of gas into a vacuum, etc. Measurements of the rate of expansion of a cloud in the upper atmosphere permitted calculating its density at a height of 430 km.



Artificial comet formed 12 September 1959 during flight of second space rocket.

By now, after ten years of observations a huge amount of material on density of the atmosphere has been obtained. Probably, the basic result of investigations is clarification of the dependence of density and temperature of the upper atmosphere on the index of solar activity, manifested in the correlation between change of orbital parameters of the artificial earth satellite and the Wolf numbers, characterizing activity of the sun, for example, flux of radio emission of the sun in the decimeter range. At present radio observation of the sun on a wavelength of 10.7 cm are usually used. The study of the sun is the key for many divisions of geophysics: processes on sun determine the temperature of the earth's atmosphere at high altitudes and as a result of this its density and change of density with increase of height, relationship between atomic and molecular components in the atmosphere, ionization in the ionosphere, its extent, composition and extent of radiation belts of the earth. It is difficult even to enumerate all aspects of the manifestation of solar activity.

It is necessary to note that almost all these phenomena are connected with variations of the ultraviolet and X-ray spectrum of the sun, since just this part of solar radiation (and also corpuscular radiation) cause the heating and ionization of the upper atmosphere of the earth. Visible solar radiation, and also infrared radiation penetrate much deeper, being absorbed either by the earth's surface, or by the surface layer of the atmosphere. Ultraviolet and X-radiation are absorbed depending upon wavelength at heights from 200 to 70 km. Therefore, study of this region of the spectrum requires the use of rockets or satellites. Historically solar rocket investigations were first, and their results probably are the most important for space flights and the protection of astronauts from destructive corpuscular radiation of the sun.

The Soviet Union carried out a study of X-radiation using geophysical rockets and artificial earth satellites. Researchers used geiger counters with windows of thin foil (~100 μm), passing radiation in narrow spectral regions (2-8, 10-20, 40-60 Å).

Radiation in these ranges of the spectrum is a sensitive indicator of solar activity and frequently precedes corpuscular ejections, which are the cause of aurore polaris, disturbances of radio communications, and also carry radiation hazard for astronauts. With the help of equipment on geophysical rockets spectrograms of X- and hard ultraviolet radiation were obtained. Identification of the many observed lines in this section is extraordinarily important in the construction of a model of the solar corona, which is the source of ultraviolet and X-radiation.

Besides this, Soviet scientists obtained excellent photographs of the solar disk in narrow spectral intervals — from several hundred angstrom to the X-radiation region near 10 Å. Angular

Demonstration of photographs of a sodium comet obtained by colleagues of the Astrophysical Institute of the Academy of Sciences Kazakh SSR at Alma-Ata (September 1959). Press conference in the Presidium of the Academy of Sciences USSR, dedicated to the launching of the robot space station Luna 2. On the right — Academician L. I. Sedov, on the left — Professor B. V. Kukarkin.

resolution on these photographs is near 1'. Comparison of photographs in the X-radiation region with simultaneously obtained photographs in visible light for rays of hydrogen and calcium lines permits studying active regions on the sun. It is possible to think that results of these investigations will lead to the exposure of criteria allowing the prediction of solar flares. Rocket observations must be examined jointly with ground results, especially with measurements of magnetic fields on the sun. It is necessary to indicate the connection of radio astronomical investigations with work in the field of the X-ray spectrum of the sun, since the solar corona is the source of radio emission on the decimeter and meter wavelengths and of X-radiation.

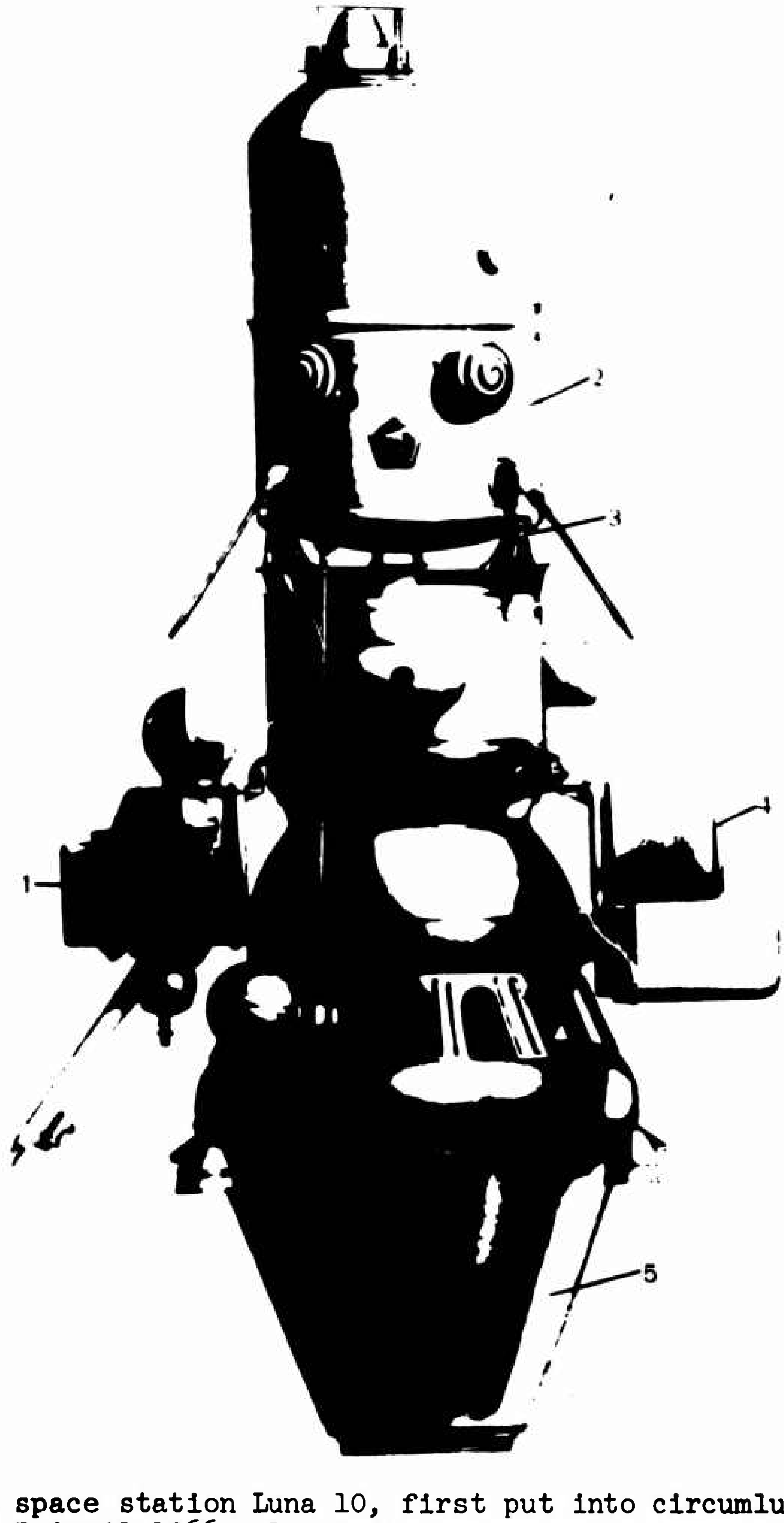
Astronomical observations during the last few years made it possible to study the distribution of neutral hydrogen in the upper atmosphere of the earth and in the interplanetary medium. Such observations, carried out in the Soviet Union and the United States on high-altitude geophysical rockets, permitted observing solar radiation dispersed in the resonance line of hydrogen L_α (λ 1216 Å). From the earth's surface such observations are impossible, since L_α-radiation is absorbed by molecular oxygen at heights of 100-120 km.

Thanks to the great optical thickness in this line radiation can be observed both on the day (illuminated by direct sunlight) and night sides of the earth. Observations showed that at night in the zenith direction to the line of sight approximately 10 times more hydrogen atoms are noted than by day. A corresponding transport theory of L_α-radiation, explaining the basic data of observations was developed. It turned out that the presence of the extended hydrogen shell of the earth — geocorona — is connected with the dissipation ("escaping") of hydrogen from the terrestrial atmosphere. Being the lightest gas, hydrogen at around 1000°K and 500 km no longer is held by the field of gravitation and "evaporates" in the interplanetary medium, creating a continuously renewed shell, which spreads at least to distances of 10-20 terrestrial radii. At such a distance the concentration of hydrogen is 100,000 times less than the concentration at a height of 500 km (level of dissipation) and composes 1-10 atoms/cm^3.

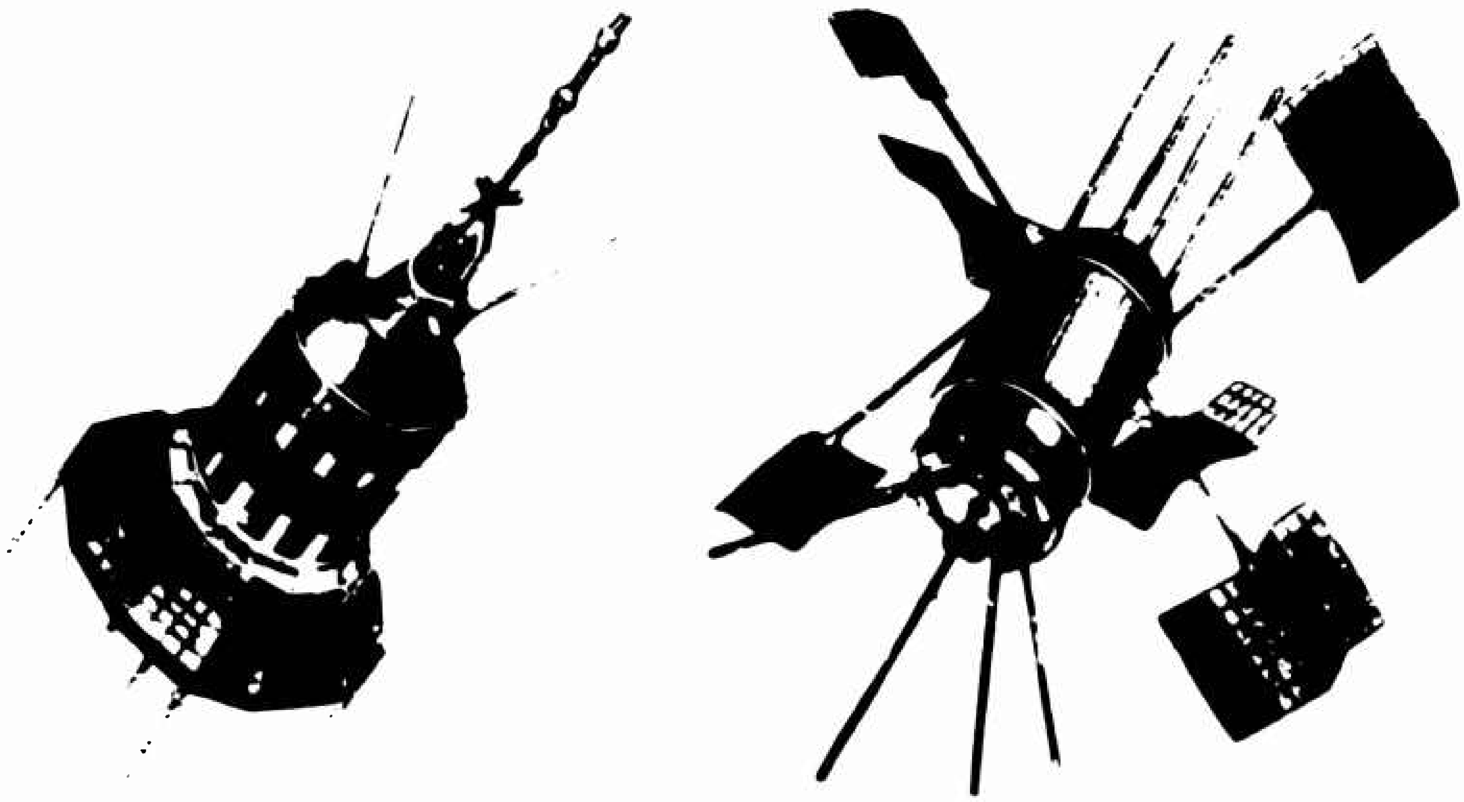
Observations carried out on the Soviet robot space stations Zond 1, Venus 2 and Venus 3, permitted tracing the geocorona to 20 terrestrial radii. These observations showed that in the interplanetary medium the concentration of neutral hydrogen is around $3 \cdot 10^{-3}$ atoms/cm^3 in an epoch of minimum of solar activity, where its temperature is not less than 10,000°K. Investigations of the ionizing component of the upper atmosphere of the earth, and also the interplanetary medium were conducted on all Soviet space rockets using charged particle traps (plasma probes). They showed that the concentration of stationary ionizing gas is less than 100 ions/cm^3. Furthermore, direct measurements were made of the solar corpuscular streams, which apparently exist continuously ("solar wind"). Their speed is around 400 km/s at a concentration of 1-10 protons/cm^3.

Similar instruments turned out to be very effective also for recording charged particles in radiation belts of the earth.

The launching of artificial earth satellites and space rockets permitted direct registration of hard meteoric substance. For the first time in the USSR the third artificial earth satellite carried piezoelectric micrometeor sensors, consisting of areas transmitting the impact of a micrometeor to a piezoelectric crystal. The intensive electrical pulse from the crystal was transmitted to earth and allowed a judgment of mass or velocity of a particle. On the basis of observations near the earth (on artificial earth satellites) and at a great distance (with automatic interplanetary probes), a condensation of dust in the environments of the earth was revealed, however, the cause of such an increase in density of the dust (by more than 10,000 times) as yet has not been clarified. It is necessary to note the observed meteor showers, which led to a short-term increase of the number of micrometeor hits. At present their concentration in interplanetary space is estimated with great uncertainty (10^{-14}-10^{-15} particles/cm^3); however, it is possible to affirm that meteoritic danger during space flights is small. The average speed and dispersion is also estimated very indefinitely.



Robot space station Luna 10, first put into circumlunar orbit 5 April 1966. 1 — radio measuring equipment; 2 — artificial moon satellite; 3 — separation system of artificial moon satellite; 4 — celestial orientation system; 5 — propulsion system.



Space system Electron, consisting of two artificial earth satellites.

In space investigations magnetic measurements are of great value. First, such measurements permitted showing a picture of the distribution of the earth's magnetic field, constructing a map of the distribution of magnetic field strength at various heights anomaly in it. Secondly, much material was obtained on the variations of magnetic field strength. The latter in turn are intimately connected with intrusion into the terrestrial magnetosphere (region where magnetic field strength is determined by terrestrial field and exceeds the value of this magnitude for interplanetary space) by solar plasma with a frozen magnetic field. A correlation of changes in magnetic field strength with charged particle fluxes was found; and also the configuration of the magnetosphere was clarified. On the illuminated side of the earth the magnetosphere is "pressed" to the earth (its height here is not more than 20,000-30,000 km), whereas on the night side it spreads to around 100,000 km, forming an elongated "tail" of charged particles held by the magnetic field. In the transition region between magnetosphere and interplanetary space a very interesting zone is revealed with chaotically oriented direction of magnetic field vector. Sensitive magnetometers measured the interplanetary stationary field, and also the field

connected with the corpuscular streams (Soviet space rockets, American Pioneer spacecraft).

The first artifical moon satellite (Luna 10) was successfully launched, and then the second and third. With artificial moon satellites (ISL) many astronomical problems connected with both the moon itself and circumterrestrial outer space can be solved. Exact investigation over a prolonged time (on the order of a month and more) of changes in parameters of ISL orbits permitted obtaining valuable data about the structure of the moon's gravitational field, and consequently, about its form and distribution of mass. It was possible to conduct a detailed study of the magnetic field in circumlunar space. Observations confirmed results obtained during flights of the first Soviet space rockets launched to the moon: the field proper of the moon is small. Revealed variations of magnetic field within the limits of 30 gammas, mostly connected with the magnetosphere of the earth, extended up to the moon orbit, due to the "blowing" effect by the "solar wind." Data were obtained about charged particles in the "tail" of the magnetosphere near the moon. Remoteness from earth permitted using the ISL to investigate longwave cosmic radio emission. The installation of radio astronomical equipment, intended for the study of kilometer radio waves (in the region of frequencies lower than 1 MHz), permits investigating the distribution of radio emission over the celestial sphere, using the effect of approach and rising of radio emission sources behind the lunar disk. Furthermore, the influence of ionosphere and powerful terrestrial radio stations is minimized. Finally, the ISL makes it possible to obtain high-resolution photographs of the surface of the moon (details around 1 m in size are fixed). Such photographs were obtained with ISL (Luna 12) and transmitted to earth. It is obvious that with identical success sections located on both the visible and invisible hemisphere of the moon can be photographed.

American researchers on the Mariner 2 spaceship measured the magnetic field strength of Venus. However, inasmuch as the ship

flew a considerable distance from the planet, the field did not register, and it can only be affirmed that it is not less than 10 times weaker than the earth's magnetic field. The equipment of the Mariner 4 did not reveal a magnetic field on Mars, which, thus, should be at least 50-100 times weaker than the earth's field. In the next few years obviously a direct method will be used to measure magnetic field strength for three bodies of the solar system — the moon, Venus and Mars, which possibly will shed light on the general theory of the nature of magnetism of revolving bodies.

The USSR in 1964 and 1965 conducted radio astronomical observations in the longwave range on the space stations Zond 2 and Zond 3, Venus 2, and also on the artificial earth satellite Electron. For this purpose antennas several meters long and highly sensitive receivers were used, working in the range of 2 MHz-30 kHz.

Observations with artificial earth satellites and rockets now draw ever greater interest from astronomers. In the first place this pertains to the recently revealed discrete sources of X-radiation and to observations of the spectra of stars in the ultraviolet range of wavelengths (United States).

The prospects of astronomical investigations with rockets and artificial satellites are extraordinarily tempting. The problem has been posed of orbiting a telescope with mirror diameter around 1 m, equipped with corresponding spectral equipment and television systems (United States, OAO project). The possibility exists of returning to earth the exposed photomaterials.

Theoretical analysis shows that it is fully practical to precisely orient artificial earth satellites to 1", with respect to stars, and perhaps even an order above. Certainly, the cost of such a project is very high; however one should consider that the extraordinarily important scientific results obtained with a telescope carried beyond the atmosphere of the earth cannot be found by any other method.

A more distant prospect will probably be the construction of an observatory on the surface of the moon.

In the region of X-ray and gamma-astronomy efforts are being directed basically toward an increase of angular resolution and area of radiation receivers. In the next few years we may expect that resolution can be brought to 1', and area of X-ray quanta counters — to several thousand square centimeters. Regarding the first task, certain prospects are opened by the method of observing the moon's occultations of discrete sources of X-radiation. Observations of sources in the region of γ-radiation would be extremely important, so far done only for the Crab nebula.

Observations of γ-quanta from the background of the sky and study of the localization of this radiation are very important for cosmology. The solution of this problem requires receivers with an area of hundreds and thousands of square centimeters with an observation time of the order of hours and even days.

By far not everything is clear in the region of X-ray, ultraviolet and γ-solar radiation, although this region of extra-atmospheric astronomy is the best developed at present.

Extensive work awaits the study of low-frequency radio emission, which cannot be observed from the earth due to the shielding action of the ionosphere. Here the problem first arises of creating antennas tens or even hundreds of meters long. Regarding the objects subject to investigation, we have first the galactic and metagalactic background, discrete sources of radio emission and the sun. Apparently for radio astronomy satellites on high orbits or even interplanetary stations similar to those from which Soviet radio astronomical investigations were carried out are preferable.

Such are the prospects of development of this new branch of astronomy in the nearest years. Rapid development of new methods of observation in astronomy, especially noticeable during the last 5-10 years, raise confidence that in the next few years much new valuable scientific information will be obtained.

Basic stages in the study of cosmic space using artificial earth satellites and robot space stations in the Soviet Union.

Date of launching	Experiment
4 October 1957	First artificial earth satellite
3 November 1957	Second artificial earth satellite with experimental animals — the dog Layka
15 May 1958	Third artificial earth satellite
2 January 1959	First space rocket with Luna 1 on board launched toward the moon
12 September 1959	Second space rocket launched to the moon (Luna 2). Rocket carried a USSR banner. First flight in the world to another celestial body
4 October 1959	Third space rocket flying to the Moon (Luna 3). Photographed and transmitted to earth an image of the reverse side of the moon from 60,000 to 70,000 km
15 May 1960	First heavy satellite vehicle, weighing 4,540 km
19 August 1960	Second satellite vehicle with experimental animals (dogs Belka and Strelka). After 17 orbital passes the ship returned to earth to an assigned region of the Soviet Union.
1 December 1960	Third satellite vehicle with two experimental animals
12 February 1961	Robot space station Venus 1, launched to the planet Venus. Put into orbit from aboard intermediate artificial earth satellite
9 March 1961	Fourth satellite vehicle with experimental animals
25 March 1961	Fifth satellite vehicle with experimental animals
12 April 1961	First astronaut in the world Major Yu. A. Gagarin accomplished a flight on the satellite vehicle Vostok. After one orbit of the earth he landed in an assigned region
6 August 1961	Flight of pilot-astronaut Major G. S. Titov, flying 700,000 km in 25 hours 18 minutes on the Vostok 2.

Date of launching	Experiment
16 March 1962	Launching of first artificial earth satellite of the Cosmos series to study circumterrestrial outer space
11-12 August 1962	Flight of several days by cosmonauts A. G. Nikolayev and P. R. Popovich on the Vostok 3 and 4
1 November 1962	Robot space station Mars 1 weighing 893.5 kg launched toward Mars. Space communication carried out at 106 million km
2 April 1963	Launching of Luna 4, weighing 1422 kg toward the moon
14-16 June 1963	Group flight of many days by astronaut V. F. Bykovskiy and the first woman astronaut V. V. Tereshkova on Vostok 5 and 6
1 November 1963	Artificial earth satellite Polet 1, carrying out maneuvers in space
30 January 1964	Launching of a system consisting of two artificial earth satellites — Electron 1 and 2 — to study the radiation belts of the earth
2 April 1964	Launching of robot space station Zond 1 for space research
12 April 1964	Artificial earth satellite Polet 2
11 July 1964	Artificial earth satellites Electron 3 and 4
12 October 1964	Flight of astronauts V. M. Komarov, K. P. Feoktistov and B. B. Yegorov on three-seated satellite vehicle Voskhod. After a flight of twenty-four hours the ship made a soft landing
30 November 1964	Zond 2
18 March 1965	Flight of cosmonauts P. I. Belyayev and A. A. Leonav on Voskhod 2, A. A. Leonov was the first to enter outer space in self-contained spacesuit
23 April 1965	Artificial earth satellite Molniya 1 for relaying television and radio transmissions interconti-nental distances

Date of launching	Experiment
9 May 1965	Robot space station Luna 5, launched for adjustment of soft landing system
16 July 1965	Artificial earth satellite Proton 1, intended for study of cosmic rays and charged particles in the environments of the earth
18 July 1965	Robot space station Zond 3. While circling the moon a large number of photographs of the reverse side of the moon is obtained and transmitted to earth
14 October 1965	Artificial earth satellite Molniya 1
2 November 1965	Artificial earth satellite Proton 2
12 November 1965	Robot space station Venus 2
16 November 1965	Robot space station Venus 3
31 January 1966	Launching of robot space station Luna 9; 3 February 1966 made soft landin on the surface of the moon
31 March 1966	First artificial moon satellite in the world: Luna 10
6 July 1966	Artificial earth satellite Proton 3
24 August 1966	Second artificial moon satellite – Luna 11
22 October 1966	Third artificial moon satellite – Luna 12. Photographs of separate sections of the lunar surface from 100 km are obtained and transmitted to earth
21 December 1966	Launching of robot space station Luna 13; 24 December 1966 made soft landing on the surface of the moon
12 July 1967	Robot space station Venus 4

STUDIES IN THE HISTORY OF ASTRONOMY[1]

Astronomy was born in the USSR very long ago. There are available data about predictions of eclipses and calendars developed in the VIIth Century AD in ancient Armenia. The great Armenian scientist of the IXth Century Ananiya Shirakatsi* wrote that the earth was spherical and correctly explained the phases of the moon and eclipses of the sun and moon. In the IXth Century the founder of algebra Mohammed al-Khowârizmî, Director of the Baghdad Observatory, was the first to try to determine the dimensions of the earth by a new method — with the help of measurements of the dip of the horizon as a mountain of known height is climbed. Another follower of al-Khowârizmî, Birune (XIth Century) wrote of the possibility of rotation of the earth and its movement around the sun, and also tried to determine the length of the terrestrial meridian. The poet and scientist Omar Khayyam (XIIth Century) wrote about the infinity of the universe and developed a most accomplished calendar. Kirik Novgorodets (XIIth Century) left to us an original composition "Ученье им же ведати человеку числа всех лет," showing him to be an outstanding expert in calendar problems. Already in the XIIIth Century there existed an active astronomical observatory in Georgia (Tbilisi). The middle of the XIIIth Century saw the creation of

[1]Translator's Note: names followed by an asterisk in this section indicate that the correct spelling was not found.

the "Ilkhanic tables" – fruit of work by the famous Maragha Observatory, equipped with a great stone quadrant and other instruments developed under Nasireddin Tusi [Translator's Note: probably Nasir al-Din]. Finally the XVth Century brought a blossoming of astronomy at Samarkand, where under Ulugh Beg outstanding astronomers worked on the creation of a star catalog.

There is no doubt that if the Mongolian invasion and 300 years of Tater yoke had not deprived us of the books and manuscripts existing in great numbers in Russia, we would have undisputable proofs of a considerable development of astronomy by the ancient Slavs. Now, relying on folklore, chronicles and such literary monuments as "Slovo o polku Igoreve" or "Khozhdeniye za tri morya Afanasiya Nikitina," we can only guess about the prehistory of astronomy in Russia. These sources contain a great deal of astronomical recordings testifying to the great observation of our ancestors, their interest toward phenomena of nature and attempts to explain these phenomena.

Over the centuries people, although closely depending upon phenomena of nature, still had no scientific knowledge about them. Therefore as a result of falsely understood ideas about the connection between the earth and the heavens, superstition and naive faith in the influence of celestial phenomena on the fate of a person became widespread. Nevertheless, for a number of reasons the Russian land did not turn out to be favorable soil for astrology. It drew feigned interest from only representatives of the ruling classes of society.

The uniqueness of the path of development of Russian astronomy in certain degree promoted subsequent propagation of materialistic tendencies in domestic science from the first steps of its formation, as far back as the time of Petrovskiy.

In 1701 at Moscow a School of Navigation was created, later (1716) transferred to Saint Petersburg as the Naval Academy. At the

School of Navigation taught L. F. Magnitskiy (1669-1739) — author of the famous "Arifmetika," a great part of which was dedicated to astronomy and navigation. Created as a project of Peter I the Petersburg Academy of Sciences (1725) soon equipped its own astronomical observatory in the tower of the Kunstkamer (Art Room) with the best instruments and made it one of the foremost in Europe.

Academic astronomers gave much attention to the cartographical needs of the extensive territory of the country. A special place in the history of Russian astronomy is occupied by "our first university" — M. V. Lomonosov whose encyclopedic mind appeared even in astronomy.

The XVIIIth Century saw the activity of the remarkable scientist L. Euler, his pupils S. Ya. Rumovskiy, J. Delisle,* P. B. Inokhodtsev, F. I. Shubert, and at the beginning of the XIXth Century V. K. Vishnevskiy.

From the beginning of the XIXth Century astronomical observatories began to appear in the universities — 1810 at Dept (V. Ya. Struve), in 1831 at Moscow (D. M. Perevoshchikov), in 1837 Kazan University (I. M. Simonov and N. I. Lobachevskiy), and then in certain other universities. In 1839 began the activity of Pulkovo Observatory, created under the leadership of V. Ya. Struve and already in the middle of the century deserving the name of "astronomy capital of the world."

Treatment of preserved archive materials will allow fuller illumination of the different stages of development of domestic astronomy. Work on turning up materials of astronomical content in the archives of the USSR still is not completed, but even now by discovered documents it is possible to judge the great value of our archives. Here are some of them which save interesting materials.

"Matenadaran" — famous repository of ancient manuscripts at Erevan. Collection began in the Vth Century AD and at present

contains more than 11,000 manuscript volumes and hundreds of thousands of archives in many, especially eastern, languages.

The Historical Museum of Georgia and the Institute of Manuscripts of Georgia are in Tbilisi. Around 500 manuscripts (starting from the IXth Century AD) are dedicated to astronomy.

The Institute of the Peoples of Asia in Moscow, its Leningrad branch, and also the Buryatskiy General Scientific Research Institute in Ulan-Ude contain interesting Indian, Arabic, Tibetan astronomical texts. Unfortunately, in the middle indologists, sinologists, tibetalogists and other students of the oriental peoples, interest toward general history and literature predominates, and astronomical texts still await study.

The Institute of Oriental Study of the Academy of Sciences, Uzbek Soviet Socialist Republic, has at Tashkent the most valuable manuscripts of astronomical character, already partially used in the publication of transactions of Birune and astronomers of Ulugh Beg's observatory.

The Academy of Sciences of the Azerbaydzhan Soviet Socialist Republic at Baku became the center of study of the Maragha Observatory and its founder Nasireddin Tusi (XIIIth Century). The collection of eastern manuscripts is kept in the library of the Academy of Sciences.

In the Archives of the Academy of Sciences of USSR are kept many documents on the history of astronomy in Russia in the XVIIIth Century, on organization, construction, equipment and activity of Pulkovo Observatory, personal collections of many outstanding Russian astronomers and foreigners working in Russia, containing their manuscripts, valuable scientific and personal correspondence and other documents.

Among them the collections of L. Euler, V. Ya. Struve, O. V. Struve, F. A. Bredikhin, A. A. Belopol'skiy, O. A. Baklund,

S. K. Kostinskiy, F. F. Shubert, V. K. Tseraskiy, K. E. Tsiolkovskiy and many others occupy a special place.

Along with materials on the history of Soviet astronomy the Archives of the Academy of Sciences USSR save valuable manuscripts and materials concerning world astronomy (manuscripts of Kepler, Regiomontagne,* papers of J. Delisle, many medieval European manuscripts, letters of Laland, and letters of many outstanding astronomers of the XIXth Century).

The departments of manuscripts of the state public libraries imeni V. I. Lenin in Moscow and imeni M. Ye. Salt'kov-Shchedrin in Leningrad save manuscripts, eastern manuscripts and personal collections of many scientists.

Astronomical observatories of the universities of Moscow, Kazan, Kiev, Odessa, Leningrad, Tartu, Vil'nyus, and also the Abastumani, Byurakan, Crimean, Tashkent and other observatories have their own archives, containing valuable and still partially unused materials connected with the activity of these observatories.

It is still necessary to mention the old instruments, globes, solar clocks and other monuments of material culture in the history of astronomy in many of our museums and at astronomical observatories. Many of them still await investigation.

Interest toward study of the history of astronomy appeared in our country in the XVIIIth Century. If we did not mention M. V. Lomonosov's lively interest in the history of the sciences, then even in the next half century after him we find a number of scientists giving special attention to the history of astronomy. It is especially necessary to note the work of P. B. Inokhodtsev (1770, 1788) and the "Short History of Astronomy" by P. Ya. Gamalea (1809). During the period of the XIXth century questions on the history of astronomy were reflected in the transactions of the most outstanding Russian astronomers — D. M. Perevoshchikov, V. Ya. Struve, O. V. Struve,

F. A. Bredikhin, A. N. Savich, I. M. Simonov (Kazan), and V. K. Tseraskiy. At the end of the century the history of astronomy in Russia occupied G. V. Levitskiy (1852-1918).

Naum Il'ich
Idel'son

1885-1951.

In the "History of Russia from Ancient Times" S. M. Solov'yev (1850-1875) collected a huge volume of material (extracted from chronicles and other sources) on different celestial phenomena observed in Russia in the Xth-XVIth Centuries. However, only in the first decades of the XXth Century did D. O. Svyatskiy especially pursue study of astronomical subjects in chronicles and in slavic folklore. His searches made it possible not only to fix the dates of astronomical phenomena, but also to trace changes of ideas about the world over the centuries. In connection with D. O. Svyatskiy's treatment of astronomical recordings in Russian chronicles an

outstanding specialist in theoretical astronomy M. A. Vil'yev (1893-1919) composed a "Canon of the Eclipses." This list of eclipses visible in the territory of Russia, was published in D. O. Svyatskiy's great work "Astronomical Phenomena in Russian Chronicles from Scientific and Critical Points of View" (1915), which supplemented his "Outlines of the History of Astronomy in Ancient Russia," published only in 1961-1966 in Nos. VII-IX of the collections "Historical Astronomical Investigations" (IAI).

In the second half of the XIXth and at the beginning of the XXth Century transactions of more general character appeared in Russia, dedicated to a history of education, for example, works of P. P. Pekarskiy and M. I. Sukhomlinov on the history of the Academy of Sciences and the Russian Academy, monographs on the history of certain universities occupied with astronomy; works on the history of separate observatories were published. However, there were no general works on the history of astronomy in our country, as there were no works with a wide scope of the history of world astronomy. In translated books (A. Berry, A. Clark, S. Arrhenius) there was a lack of information on the history of Russian astronomy on the part of authors.

After the Great October Socialist Revolution N. I. Idel'son (1885-1951) occupied a conspicuous place among astronomer-specialists studying the history of science. His work on the history of astronomy is the subject of an article by S. N. Korytnikov in "Historical Astronomical Investigations" (No. IV, 1959). N. I. Idel'son was a widely learned astronomer and specialist in celestial mechanics and position astronomy. His analysis of the history of astronomy and his characteristic of scientists of the past always differed by accuracy and imaginations. The connection of the development of scientific ideas with the development of society deeply interested N. I. Idel'son. Unfortunately, his premature death deprived us of a brilliant researcher and recognized authority in the history of astronomy. To Idel'son belongs a series of works dedicated to the classics of astronomy — Copernicus, Galileo, Kepler, Newton, Clairaut,

Lomonosov, Lobachevsky, Leverrier, Lagrange and others. It is especially necessary to note his small but excellent book — "History of the Calendar" (1925).

In prewar years S. N. Blazhko (1870-1956) on the basis of treatment in depth of archives composed a "History of the Astronomical Observatory of Moscow University in Connection with the History of Teaching in the University (1824-1920)," augmented by articles of S. V. Orlov on the history of the Astrophysical Institute and P. P. Parenago on the Astronomical-Geodesic Institute and the Institute imeni P. K. Shternberg.

During the years of the Great Patriotic War (1941-1945) interest toward the history of domestic science increased strongly. After the war began an intensive study of archive materials and old, half-forgotten publications. This led to a series of valuable findings, restoration of the first position of certain remarkable investions and discoveries undeservedly forgotten and later newly "discovered" abroad, while not always independently. In particular, the first position of V. Ya. Struve in determination of the distances to the stars (A. N. Deych) and the first position of M. A. Koval'skiy in substantiation of the idea of rotation of the Galaxy (D. Ya. Martynov) were fixed. Furthermore, in various places were revealed rich repositories of important documents on the history of domestic science, including astronomy.

In connection with this interest toward the history of Russian science it is necessary to note the 1951 book by the noted historian of astronomy Yu. G. Perel' (1905-1964) "Outstanding Russian Astronomers" and the extensive work conducted in the USSR on an annotated reprinting (sometimes the first in the Russian language) of the works of outstanding workers in Russian astronomy. Every such republication was accompanied by a biography, detailed analysis of scientific activity and extensive commentaries. Such were the works of M. V. Lomonosov on astronomy, collected in the fourth volume of the complete collection of his compositions (1955), A. A. Belopol'skiy's "Astronomical Transactions" (1955), F. A. Bredikhin's

investigations "About the Tails of Comets" and "Studies About Meteors" (1955), M. A. Koval'skiy's "Selected Work in Astronomy" (1952), V. Ya. Struve's "Studies in Stellar Astronomy" (1953), V. K. Tseraskiy's "Selected Work in Astronomy" (1953) and others.

First attempts to describe great periods in the history of domestic astronomy were made in articles by V. G. Fesenkov "Description of the History of Astronomy in Russia in the XVIIth and XVIIIth Centuries" and B. A. Vorontsov-Vel'yaminov's "History of Astronomy in Russia in the XIXth Century" ("Transactions of the Institute of the History of Natural Science and Technology, Academy of Sciences USSR," Vol. 2, 1948). In 1956 appeared a book by B. A. Vorontsov-Vel'yaminov "Outline of the History of Astronomy in Russia," and in 1960 his book "Descriptions of the Development of Astronomy in the USSR." This was the first developed account of the history of astronomy in our country from antiquity up to the present. B. A. Vorontsov-Vel'yaminov also wrote chapters on the history of astronomy in the three-volume "History of Natural Science in Russia" (Institute of the History of Natural Science and Technology, Academy of Sciences USSR, 1957-1960).

One direction of the development of the history of domestic astronomy was the composition of an outline history of different astronomical observatories.

Thus, for example, the history of the famous Pulkovo Observatory was widely illustrated in collections in connection with the 100th anniversary of the observatory (1939), with the opening of the rebuilt observatory after the war (1953), and also with the 125th anniversary, coinciding with the 100th year after the death of V. Ya. Struve (1964).

Before going to a description of the activity of several centers of scientific research work on the history of astronomy, it is necessary to note that in connection with archeological excavations of the famous Samarkand Observatory materials were studied concerning

the life of the politician and scientist of the XVth Century Ulugh Beg (T. N. Kary-Niyazov) and outstanding astronomers working at the Samarkand Observatory: Kaze-zade Rumi,* Dzhamshida Giyaseddina,* Ali Kushchi* and others.

History of astronomy in Central Asia is an essential part in the history of so-called Arabic astronomy. Use of this term, as also other attempts to talk about "Arabic culture" without analysis of its component parts, was a manifestation of false historical conception of Pan-Arabism, in accordance with which the contributions of peoples conquered by the Arabs, including peoples of Central Asia and Transcaucasus, records the activity of only some Arabs. Soviet historians of astronomy are occupied by restoration of historical truth with respect to the contribution to science of peoples populating Central Asia and the Caucasus. During the last few years many astronomical manuscripts were found showing a high development of astronomy in Georgia and Armenia even at the end of the first millenium AD. Reflected in literature was the activity of the Armenian scientist of the VIIth Century Ananiya Shirakatsi (A. G. Abramyan, B. Ye. Tumanyan) and the outstanding worker of the XIIIth Century Nasireddin Tusi and his famous Maragha Observatory, founded in 1259 (G. D. Mamedbeyli*). The "Ilkhanic tables" of Tusi, just as the Samarkand tables of Ulugh Beg were known to all scientists of the world. One more name especially attracted the attention of the historians of science, including historians of astronomy, the name of the great encyclopedist of the Xth to the first half of the XIth Century Birune (U. Kh. Sadykov, V. P. Shcheglov, G. D. Dzhalalov). In 1950 a collection of articles dedicated to the 900th year since the death of Birune was published. The first three volumes of the works of Birune were published in Tashkent by the Academy of Sciences of the Uzbek Soviet Socialist Republic in 1957-1966. Works were published of the scientist, philosopher and poet Omar Khayyam (c 1040-1123), who wrote about the infinity of the world in space and in time and, furthermore, is considered the author of a calendar more precise than the Gregorian calendar.

It is especially necessary to mention a book of P. A. Startsev "Outline History of Astronomy in China" (1961) — the first consecutive account of Chinese astronomy from the most ancient times until the present. Interesting pages of the history of astronomy in Mongolia were illustrated in the articles of L. S. Baranov.

In many scientific establishments the last decades have seen intensive work in the history of astronomy. A great center of study on the development of domestic science of the XVIIIth Century and, of course, the history of astronomy, was the museum of M. V. Lomonosov at the Leningrad division of the Institute of History of Natural Science and Technology, the Academy of Sciences USSR. The works of V. L. Chenakal illustrate questions on the history of the academic observatory in Petersburg and the history of projects of small academic observatories. The book "Descriptions of the History of Russian Astronomy. Observational Astronomy of the XVIIth and Beginning of the XVIIIth Centuries" (1951) and a number of articles illustrate the history of the conception of astronomy in the Petersburg Academy of Sciences. The book "Russian Instrument-Makers of the First Half of the XVIIIth Century" (1953) illustrates the activity of Russian creators of astronomical instruments. A special cycle of investigations of V. L. Chenakal was dedicated to business connections of the English telescope masters with Russia. A commentary to the complete collection of compositions by M. V. Lomonosov was based on voluminous archive materials especially examined and studied by V. L. Chenakal.

A cycle of works by P. M. Gorshkov was dedicated to the history of astronomy in Petersburg-Leningrad University and its outstanding representatives.

S. N. Korytnikov carried out extensive work on the study of past astronomy in Kazan. He found many valuable archive materials and published them with detailed commentaries illustrating activity in the region of astronomy by I. M. Simonov, N. I. Lobachevskiy, M. A. Koval'skiy, D. I. Dubyago, V. P. Engelhardt and many other

Kazan scientists. Showing special interest toward scientific connections of Moscow and Kazan, S. N. Korytnikov turned to the brilliant personality of the founder and first director of the Moscow Observatory D. M. Perevoshchikov, dedicating to him a series of valuable investigations.

In Tashkent a cycle of works dedicated to the history of Tashkent Observatory and its outstanding workers flowed from the pen of V. P. Shcheglov. Three volumes of a collection of the work of Birune appeared. Birune's ideas of the possibility of motion of the earth around the sun were bold attempts for his time to escape the shackles of the geocentric Weltanschauung. G. D. Dzhalalov besides studying work of the Samarkand astronomers of the XVIth Century published "State of Indian Astronomy Prior to the Time of Birune" (IAI, IV).

In Baku (Academy of Sciences AzSSR) G. A. Mamedbeyli carried out extensive work on the study of activity of the Maragha Observatory and its famous founder and astronomer of the XIIIth Century Nasireddin Tusi.

In Erevan A. G. Abramyan, B. Ye. Tumanyan and other Armenian researchers relying on inexhaustable wealth of "Matenadaran," illustrated the history of astronomy in Armenia starting from the VIth Century AD. In 1964 appeared the first volume "History of Armenian Astronomy" by B. Ye. Tumanyan (in Armenian with a summary in Russian and English), embracing the interval of time before the beginning of the XIX Century. The activity of the remarkable scientist and encyclopedist of the VIIth Century Ananiya Shirakatsi, calendarist O. Imastaser* (end of XIth — beginning of XIIth Century) and many other scientists is illustrated and a description given of old instruments — astrolabes, solar clocks, lunar indicator, star charts and astronomical tables, created in Armenia in the past century.

In Georgia the history of Georgian astronomy is studied (G. G. Georgobiani), represented in the state museum of Georgia at Tbilisi

by manuscripts of the IXth and later centuries. There is special interest in calendar problems, studied since ancient antiquity, and the question about the astronomical observatory, which existed in Tbilisi even in the XIIIth Century.

The Baltic republics are conducting valuable research in the history of development of astronomy in Lithuania, Latvia and Estonia. In particular, the past of the Tartu Observatory and the first period of scientific activity of V. Ya. Struve was studied in detail (G. A. Zhelnin and P. V. Myursepp*), activity of the outstanding expert in optics Bernhardt Schmidt (P. V. Myursepp), history of astronomy in Lituania (P. V. Slavenas), history of astronomy in Latvia and scientific activity of P. Bol' and F. Blumbakh (I. M. Rabinovich).

In Moscow a cycle of researches concerning Soviet workers of the XVIII and XIX Centuries was carried out by Yu. G. Perel', who brought to life certain honored and forgotten names and revealed a series of new material about P. B. Inokhodtsev, P. Ya. Gamalea, M. M. Gusev, V. F. Fetsorov, V. K. Vishnevskiy and others. As a result of a survey of a huge amount of material Yu. G. Perel' published the study "From Domestic Astronomical Historiography," to which he appended a valuable bibliography of numerous publications, including encyclopedic and bibliographic dictionaries and sets of old journals containing information about the workers of Soviet astronomy.

Another cycle of work by Yu. G. Perel' touched on outstanding scientists of the west, their connections with Russian science or their influence on its development. Here pertain works dedicated to Lambert, Voltaire, Humboldt and others. From these investigations appeared his book "The Development of Concepts About the Universe" (published in 1958 and 1962), in which from positions of dialectic materialism the development of opinions on the universe are analyzed for various peoples and in different epoches, starting from ancient antiquity and finishing with contemporary ideas about the universe.

I. N. Veselovskiy conducted a series of valuable investigations of ancient astronomy. In connection with preparation of a complete translation of the "De Revolutionibus" of Copernicus and certain other of his works (published in 1964 with extensive commentaries of the translator and a piece by Acad. A. A. Mikhaylov about Copernicus) he translated the "Almagest" of Ptolemey, translated and published the "On the Magnitude and Distances of the Sun and Moon" by Aristarchus of Samos. P. G. Kulikovskiy published the book "M. V. Lomonosov – astronomer and astrophysicist" (1961) and "Pavel Karlovich Shternberg" (1965). A series of interesting works came from colleagues of the Institute of History of Natural Science and Technology, Academy of Sciences USSR. Thus, L. Ye. Maystrov published a series of articles containing a description and interpretation of old Russian wooden carved calendars, and also runic calendars preserved in different museums of the USSR. Work on finding and analyzing astronomical information in ancient Russian chronicles is being carried on by V. K. Kuzakov.

A serious contribution to the history of astronomy was the scientific biography of the outstanding Soviet astronomer F. A. Bredikhin, written by N. I. Nevskaya (1964).

Z. K. Sokolovskaya (Novokshanovoy) completed thorough biographies of the military geodesists F. F. Shubert (1958) and I. I. Stebnitskiy (1960), an investigation of astronomical and geodesic instrument making in Russia, and also a large scientific biography of V. Ya. Struve (1964). A. Ye. Medunin studied the development in Russia of gravimetry and theory on the figure of the earth from 1725-1917 (1964).

A sizable study of the cosmologic and cosmogonic ideas and discoveries of the great English astronomer William Herschel was published by A. I. Yeremeyev ("The Universe of Herschel," M., 1966). Ye. K. Straut conducted extensive research on the history of study of the surface of the moon – a problem which obtained special urgency in connection with successes in mastering outer space.

Publication and republication in Russian of the classics of world astronomical literature was of specific value, starting with the translation by A. N. Krylov of "New Theory of the Moon's Motion" by Euler (1934), his translation of "Mathematical Beginnings of Natural Philosophy" by Newton (1936), publication of "Theory of the Figure of the Moon" by Clairaut (1947) and finally the "Dialogues" of Galileo, "Dialogues" of Jordan Bruno, collections of articles in connection with anniversaries of Newton, Galileo and Copernicus.

In connection with preparation of the second edition of the Bol'shaya Sovetskaya Entsiklopediya serious work was conducted on finding and definitizing all data about the workers of astronomy, including those Soviet scientists whose names had accidently become lost in recent time. Together with this progressed individual questions on the history of astronomy in Russia, composition of biographies of astronomers and description of the development of different observatories.

In 1952 in the Astronomical Council of the Academy of Sciences of the USSR was created a Commission on the History of Astronomy (KIA) for coordination of plans and assistance in the works of our country on the history of astronomy. The final target was the composition of a history of domestic astronomy in connection with the general historical development of the country and in interaction with the development of world astronomy. In connection with this the commission rendered all possible assistance to finding and using archive materials, and the development of particular questions, i.e., preparation of those materials on the basis of which the composition of an exhaustive general description of the history of Soviet astronomy subsequently will become possible. It especially looked after the inclusion of investigations in the history of astronomy in the plans of astronomical establishments of allied republics, in particular the Georgian, Armenian and republics of Central Asia. However, a first priority problem of the commission was organization of the publication of research in the history of astronomy.

In 1954 the State Technical Press (later Fizmatgiz) supported the initiative of the commission of the History of Astronomy of the Astrocouncil Academy of Sciences USSR in publication of nonperiodic collections "Historical Astronomical Investigations" following the example of the already widely acknowledged "Historical Mathematical Investigations."

In 12 years appeared nine numbers of the IAI, 4134 pages in which more than 70 authors published over 100 scientific investigations, articles and results of archive findings. It is necessary to note participation in the IAI of foreign scientists: D. Nador (Hungary), Ye. Rybki, V. Zonna and K. Rudnitskiy (Poland), G. Dingle (England), S. Gaposhkin (United States), V. Petri (FRG) and others. The collections carried large studies: "Brief Description of the History of Practical Field Astronomy in Russia" M. K. Venttsel' (IAI, II, 7-140, bibliography: 22 entries), "The History of Development of Astrospectroscopy in Russia and in the USSR" O. A. Mel'nikov (IAI, III, 3-260, bibliography: 1200 entries), "Description of the History of Astronomical Bibliography" N. P. Yerpylev (IAI, IV, 13-250, bibliography: 185 entries), "Description of the History of Astronomical Bibliography" N. B. Lavrovaya (IAI, V. 83-196).[1] Many original works were published in the following divisions of IAI:

1) descriptions of the activity of Soviet astronomers founded on archive materials [V. K. Vishnevskiy (IAI, I), I. I. Simonov (I), V. K. Tseraskiy (I), D. M. Perevoshchikov (II), S. P. Glazenap (III), A. D. Krasil'nikov (III), S. K. Kostinskiy (III), A. K. Kononovich, V. P. Engelhardt (IV), N. G. Kurganov (VI), N. Ya. Tsinger (VII), M. F. Khandrikov (VIII) and R. F. Fogel' (IX) and others];

2) detailed investigations of the activity of our contemporaries — deceased G. A. Shayn (III), N. I. Idel'son (IV), A. D. Dubyago (VII) and P. P. Parenago (VII), and V. V. Kavrayskiy (IX);

[1]A supplement to this valuable work is "Bibliography of Astronomical Bibliographies" by N. B. Lavrovaya, published by the Astrocouncil of the Academy of Sciences USSR in 1962.

3) investigations of the activity of the classisists in world astronomy and translations of their works: Aristarchus of Samos (articles of I. N. Veselovskiy and translations of the only work left to us of the ancient Greek scientist, containing determination of distances and dimensions of the sun and moon, IAI, VII); Nicholaus of Orem* (study by V. P. Zubov and the first Russian translation of "Treatise about Commensurability or Incommensurability of Motions of the Sky," VI); Birune ("Star Catalog" translated by B. A. Rozenfel'd, VIII); Copernicus (Birth of "De Revolutionibus" — article by I. N. Veselovskiy in IAI, VI); Hevelius (P. G. Kulikovskiy, VII); Galileo (G. Dingle, IV); John of Snyadet* (Ye. Rybka, II); M. Pochobute* (V. L. Chenakal, VII); Leverrier (postumous publication of report by N. I. Idel'son, IV);

4) investigations dedicated to the history of instruments. In the first place one should note the cycle of articles by V. L. Chenakal, dedicated to astronomical observatories of the Petersburg Academy of Sciences in the XVIIIth Century (IAI, I, II, III), and his article about the English masters (Bird,* Short and others), who prepared astronomical instruments for Russia. Furthermore, medieval instruments, kept in the USSR were studied and described. This includes the lunar indicator — an instrument of the XIVth Century, made from parchment, at present kept in the Erevan "Matenadaran" (article of B. Ye. Tumanyan in IAI, VI); XVIth Century astrolabe of Gualterus Arsenius,* kept in the M. V. Lomonosov Museum (article of V. L. Chenakal, IAI, VII); Armenian astrolabe of the end of the XVIIth Century (described by B. Ye. Tumanyan in IAI, V).

The history of domestic instrument making was also the subject of researches by Z. K. Novokshanova "Pulkovo Mechanics — Creators of Astronomical and Geodesic Instruments" (IAI, III) and "Mechanical Workshop of the First Order" (IAI, VIII).

One contemporary astronomical instrument is told of in an article by D. N. Ponomarev "History of the Creation of the Photographic Zenith Telescope" (IAI, VII).

Methodological and general-philosophical foundations of the history of astronomy were the subjects of an article by B. V. Kukarkin (IAI, VII, 1961; IX, 1966). P. G. Kulikovskiy published the article "Certain Questions of the History of Astronomy" (IAI, VII, 1961), which gives the chronology of the most important events in the history of Russian and Soviet astronomy. Every date is reinforced by reference to original or most complete literary sources. This article can help those western historians who sincerely want to illustrate objectively the contribution made by various peoples in the development of astronomical science.

Every issue of IAI was completed by an annotated chosen bibliography of the most considerable transactions published on the history of astronomy in world literature for the preceding year or two. The increase of interest toward IAI from foreign historians of science promoted the fact that starting with No. IV IAI was accompanied by an English translation of the table of contents and preface of the editorial board. This interest appeared also in "British Journal on the History of Sciences" (Vol. I, No. 4, 1963; Vol. II, No. 5, 1964) as a survey of eight numbers of IAI, compiled by P. G. Kulikovskiy.

In recent years in the development of questions connected with history of astronomy have joined specialists and historians not working in astronomical establishments. This serves as a characteristic index of the growth of interest toward the history of astronomy in wide circles of intelligentsia.

Special attention was turned to the prehistory of astronomy as a science — the people's astronomy. After publication of the pithy "Outline History of Astronomy in Ancient Russia" by D. O. Svyatskiy (IAI, VII-IX) and the small book of Kh. Abishev "Elements of Astronomy and Weather in the People's Work of the Kazakhs" (Academy of Sciences of Kazakh SSR, 1949) followed by certain others, for example articles of P. K. Pryuller on the Estonian people's astronomy (IAI, IX, 1966).

KIA conducts its own plenums, at which, besides the solutions to scientific and organizational questions, various scientific reports are discussed. Reports on these plenums were published in "Astronomical Journal," "Herald of the Academy of Sciences USSR," and recently in "Reports of KIA."

Very valuable materials for treatment of the history of development of separate regions of domestic astronomy after the Great October Socialist Revolution are contained in the collections "Fifteen Years of Astronomy in the USSR," Thirty Years of Astronomy in the USSR," "Forty Years of Astronomy in the USSR" (contains a huge bibliography on all divisions of astronomy, including the history of astronomy and more than 550 names) and, finally, this anniversary collection.

Scientific and popular work in the history of astronomy in recent years has also attained wide development, which was expressed in the publication of a number of books and collections, and also a series of articles "Memorable Dates," which appear in "Astronomical Calendar," in "Brief Astronomical Calendar of the Academy of Sciences Ukrainian SSR" and in other publications. It is necessary also to note articles on the history of astronomy published in popular science journals ("Priroda," "Nauka i zhizn'" and others) in connection with anniversary dates, and also the book recently appearing (1966) in a series of bibliographies on the history of science and technology, A. I. Yeremeyeva's "Outstanding Astronomers of the World."

Let us note the 1966 book of the renowned Dutch astronomer and public worker A. Pannekoek "History of Astronomy" (translated by N. I. Nevskaya). The year 1965 saw the beginning of a new popular science journal "Zemlya i Vselennaya," which gives over pages to interesting historical astronomical publications.

The historians of astronomy have taken active participation in interdepartmental conferences on the history of the physical and mathematical sciences, called in 1960 and 1963 by the ministry of

higher education of the USSR at Moscow State University, and at conferences of the Soviet National Unification of Historians of Natural Science and Technology. Departments of the history of astronomy discussed scientific reports, published later in "Questions of the History of the Physical and Mathematical Sciences" (publishing house Vysshaya Shkola, 1963) and in the collection "Methodology and History of Science," No. 4, "Physical and Mathematical Sciences (publishing house of Moscow State University, 1966).

Research work conducted by the USSR, numerous publications on the history of astronomy, and in particular publications of IAI, and active participation in work of Commission 41 (History of Astronomy) of the International Astronomical Union (IAU) conditioned the advancement of the Soviet representative (P. G. Kulikovskiy) in 1958 and 1961 at the Xth and XIth IAU Congresses to the post of President of Commission 41. The President of Commission 41 for 1958-1964 was able to organize the publication of "Information Circular of Commission 41" (following his example circulars of certain other IAU commissions began to be issued), composition (with the ready assistance of the chief bibliographer of GAISh N. B. Lavrovaya) and yearly publication of a bibliography of world literature on the history of astronomy (bibliographies came out for 1960-1966). At the XIth IAU Congress in 1961 at Berkeley Commission 41 initiated the diaplay "Remarkable Pages of the History of Astronomy," in which interesting exhibits of many countries were represented. Before the XIIth IAU Congress in 1964 at Hamburg (FRG) took place the first International Symposium on the History of Astronomy, convoked by the International Union of Philosophy and History of Science and Commission 41 of IAU. More than 80 scientists from 18 countries participated in the discussion of two great scientific problems: history of development of the technology of astronomical observations in connection with development of astronomy itself and basic questions of astronomical historiography.

For participants of the symposium and the XIIth IAU Congress an exhibit of old tools, instruments and documents was organized under

the name "Documenta Astronomica." Transactions of the symposium were published in volum[illegible] the collection "Horizons of Astronomy" (Cambridge, Engla[illegible]). It also included reports by V. L. Chenakal "Old Astronomical Instruments in Museums of the USSR," B. Ye. Tumanyan's "History of Astronomy in Armenia in Materials of the Repository of Ancient Manuscripts 'Matenadaran,'" and P. G. Kulikovskiy's "Materials on the History of Astronomy in Archives of the USSR."

At the initiative of Commission 41 the executive committee MAS at the 1964 congress proposed a new form of participation in work of the IAU — the category of consulting members of the separate commissions. Consulting members are invited scientists who are not on the staffs of astronomical establishments, but who seriously study problems facing the commission. Commission 41 placed around 20 scientists of various countries in the number of consulting members.

Success of the first International Symposium on the History of Astronomy was secured in one of the resolutions of Commission 41, by which the historians of astronomy — representatives of the various countries — were given the problem of creating in the next few years a multivolume (3-4 volumes) international monograph on the history of astronomy.

The members of Commission 41 (history of astronomy) are at present N. P. Yerpylev, P. G. Kulikovskiy, P. V. Slavenas and V. L. Chenakal (member of the Organizing Committee of the Commission).

In August, 1965, Soviet historians of astronomy participated in the XIth Congress of the International Union of [illegible]losophy and the History of Science at Warsaw and Krakov. Reports [illegible] P. V. Myursepp, B. Ye. Tumanyan, and V. L. Chenakal at sessions of the section of history of astronomy will be published in "Trudy XIth Congress MSFIN." A special conference convoked by the current President of Commission 41, the Polish scientist Ye. Rybka, discussed the

preliminary plan of the monograph on the history of astronomy.

Work conducted in the USSR during the last 50 years on the history of astronomy is a guarantee that the contribution of the peoples of the Soviet Union in the development of astronomy will be reflected in this international monograph in accordance with the actual role which the scientists of Central Asia and the Transcaucasus in the Middle Ages, and later Russian and Soviet astronomers played and continue to play in the development of world science. This of course requires further intense work on the study and publication of archive materials, ancient manuscripts and descriptions of the real monuments of the history of astronomy in our country.

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The Planets and Their Satellites[1]

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[1] Works from 1917-1956 omitted for lack of space. See "Astronomy in the USSR over the Last Forty Years," Fizmatgiz, 1960.

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Sun[2]

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[2] *За недостатком места невозможно привести сколько-нибудь полный и исчерпывающий список основных работ по физике Солнца за рассматриваемый период. Полный список работ, выполненных в нашей стране до 1957 г., приведен в отличном обзоре В. П. Вязаницына «Солнце» в сборнике «Астрономия в СССР за 40 лет» (М., Физматгиз, 1960). Прилагаемый краткий список (с указанием проблемы) включает лишь некоторые книги, обзоры или обзорные статьи, в которых читатель может найти важные дополнения к списку указанного сборника.*

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